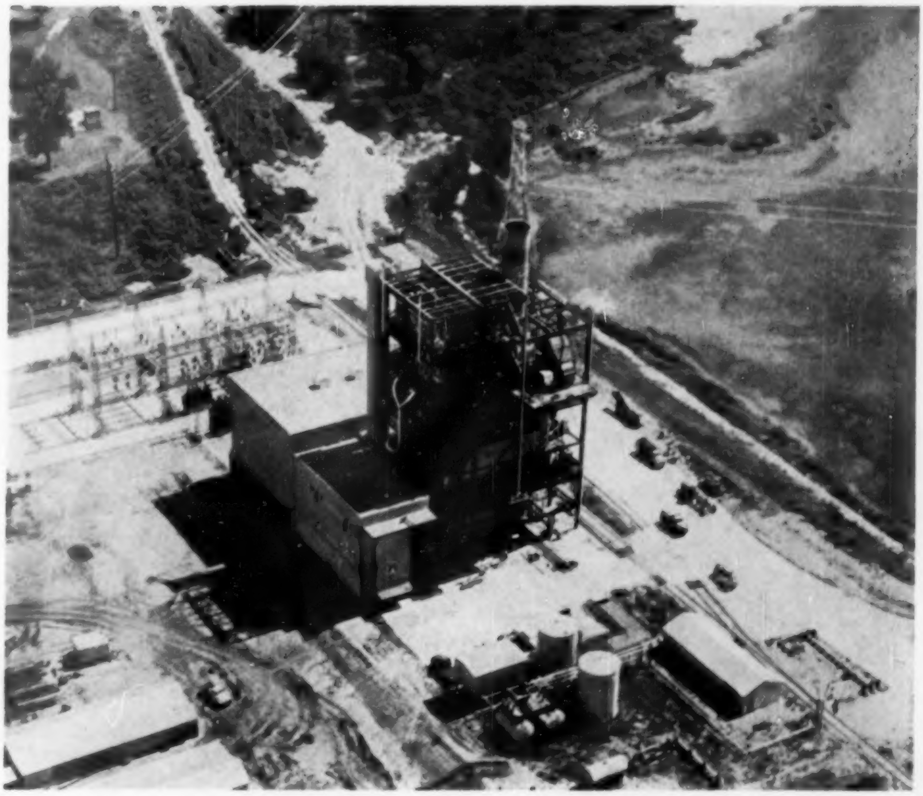
Combustion

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION



November 1960

Combustion Mechanism of Pulverized Coal

Twenty-First Annual Water Conference

115 Mw Station For $82.12/kw

Combustion

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

volume 32 number 5 **November 1960**

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BPA

Printed in U. S. A.

COVER PHOTO

Aerial view of the new 115 Mw Holly Street Station of City of Austin, Texas. Three more units are planned for this site.

ANACONDA CONDENSER AND HEAT EXCHANGER CLINIC

"Cupralum," lead-surfaced Anaconda copper tube, offers practical answers to some tough corrosion problems

If you'd be interested in more compact, more economical heat transfer units for handling corrosive liquors — sulfuric, chromic, phosphoric acids, sulfites, sulfates, alum, and the like — you should know about Cupralum*. Cupralum, a product of Knapp Mills, Inc., is Anaconda copper or copper-alloy tube to which a uniform, dense-structured, extruded chemical lead surfacing has been metallurgically bonded.

Alfred P. Knapp, chairman, Knapp Mills, Inc., explains to visitors how his company's patented drawing process metallurgically bonds lead surfacing to copper tube.

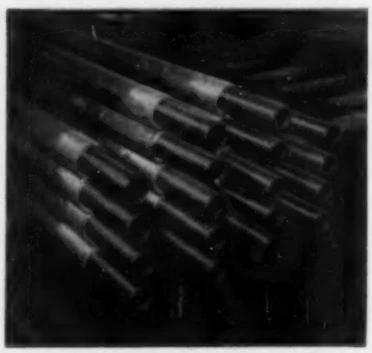
THE OUTSIDE lead surface, which may be from ⅛" to ½" thick, resists concentrations of acids—of sulfuric acid, for example, up to about 85% and up to 428 F. Being bonded to the copper, it expands and contracts with the copper during temperature cycling. Without the metallurgical bond, the lead would creep and eventually fail—an inherent weakness of all-lead tubing.

Two U-bend Cupralum tube bundles like this are used in a Ferrolum (lead-surfaced steel) separator tower to boil off ammonia from a urea carbonate ammonia solution—in the production of urea fertilizer. Anaconda copper tube core 1" O.D., 12 gauge, handles 150-lb. steam. Lead surface is ¾ inch thick. Separator tower operates at 145 C (293 F) and 240 psi.

THE COPPER or copper-alloy tube inside provides strength to make Cupralum self-supporting — and to stand steam pressures up to 150 psi in standard wall thicknesses offered. It also provides its high corrosion resistance internally to cooling waters, steam, and refrigerants.

Most important, copper offers its high heat transfer rate. Because of the metallurgical bond with the lead, the over-all heat transfer rate of Cupralum is high—higher than all-lead tube and higher than that of iron and steel.

THE NET RESULT is that a given heat transfer job can be done with fewer square feet of surface — for a more compact unit. Or it is possible to get increased capacity in present existing space.

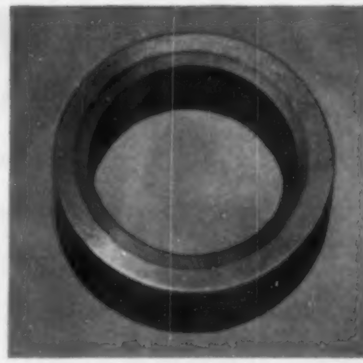


Lead surfacing removed from ends of Cupralum tubes preparatory to insertion in lead-clad steel tube sheet. Tube ends are usually rolled, but for severe thermal cycling service, may be brazed to outer steel face of tube sheet.

In many cases, the first cost of the coil is lower. Usually this is true where higher steam pressures than those previously used are available—or where expensive, hard-to-fabricate alloys have been used. Improvement of the heating or cooling cycle is another source of savings. Under any circumstances, a long operating life and easy maintenance provide over-all economy.

NUCLEONIC APPLICATIONS. Cupralum with a thicker surfacing of lead is being used increasingly in the nuclear industry. For gamma shields that must be cooled, Cupralum coils are built in to provide efficient heat transfer from the shield to the cooling medium.

Where radioactive liquors and spent resin discharge from demineralizers must be conveyed through process piping into process vessels for concentrating the radioactive solution, Cupralum piping prevents the escape of gamma radiation. In nuclear applications, the lead surfacing may be 1" to 8" thick.



Cutaway section of Cupralum tube. It is produced in 20' lengths or in long continuous coils —from 40' to 100' depending on diameter. It is easy to bend and fabricate. Reliable jointing techniques have been developed.

Lead surfaces of Cupralum tubes and of tube sheet are fused by lead-to-lead welding. Then an extra thickness of lead is applied at the joint for extra protection.

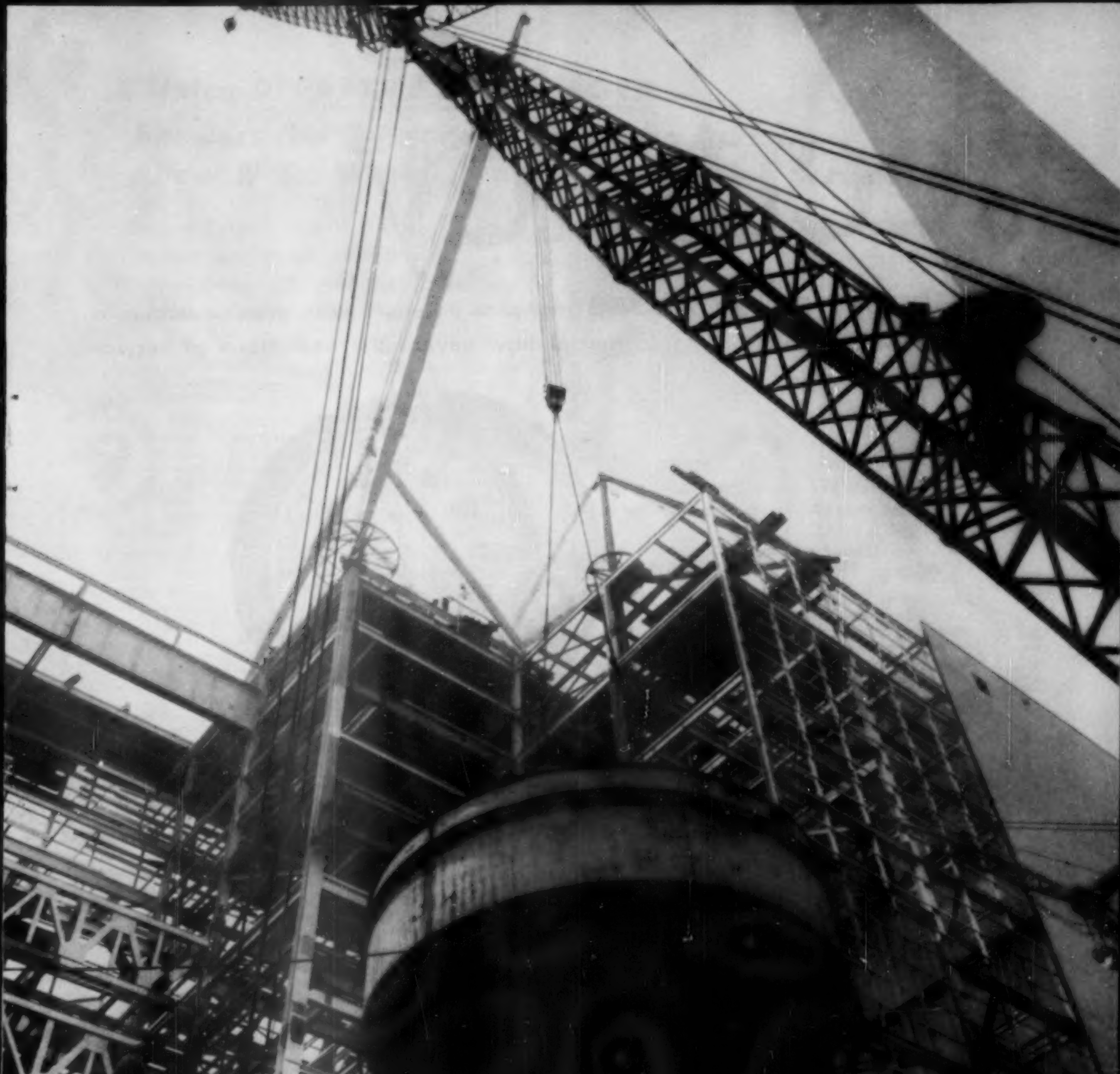
FOR MORE INFORMATION. For detailed data on Cupralum, write Knapp Mills, Inc., Wilmington, Del. Or see your Anaconda representative, who can also provide data on the full line of Anaconda copper and copper-alloy tubes—arrange for technical assistance in meeting special corrosion and heat transfer problems. Anaconda American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ont.

*Registered trademark of Knapp Mills, Inc.

ANACONDA®

TUBES AND PLATES FOR CONDENSERS AND HEAT EXCHANGERS

Anaconda American Brass Company



A Nalco DEPARTMENT MANAGER

Answers the Questions Most Often Asked About Nalco Water Treatment Consulting Service

Experts Extend Your Staff Potential for Fast, Economical Handling of System Design, Chemical and Equipment Selection, and Plant Operations.

Question: If a company's staff includes qualified design and operating personnel, why is Nalco Consulting Service needed?

Answer: Design, modification, improvement, and achievement of maximum economy in operation of water treatment facilities are highly specialized chemical engineering fields. Constant research and long experience in these fields enable Nalco engineers to supplement—*not* replace—the efforts of a company's staff by providing up-to-date information in their special fields.

Question: How does Nalco Consulting Service differ from the services of design consulting engineers?

Answer: Again, remember the specialized nature of water treatment engineering. Rarely can a company or consulting firm afford to maintain a staff of engineers who devote their entire energies to water treatment. Nalco, however, *does* have such a group of water treatment specialists that can act as an extension to the staff of the design engineer. These men have not only knowledge and experience in the intricacies of each of the specialized areas of water treatment, but the constant association with the rapidly changing technology of the field required to keep their information accurate and up-to-date.

Question: What return on investment does the cost of a Nalco consulting program provide?

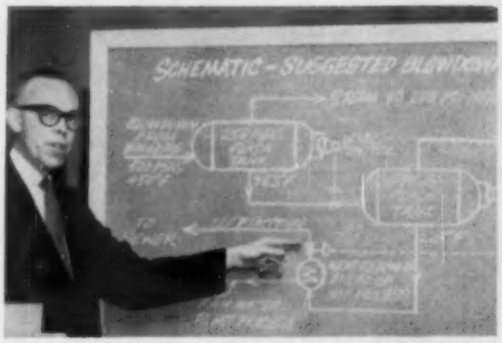
Answer: Nalco Consulting Service reduces plant construction costs and saves *your* engineers' time. For example, assume that you need a new or completely modernized ion exchange water treatment plant. Nalco Consulting Service will help your engineers and/or design consultants establish the basic type and size of plant needed, *before* requests for bids are issued. Potential suppliers can then return bids faster and more economically. Also, your engineers can evaluate bids in a fraction of the time required for evaluation of bids on a variety of plant types. This reduces the overall cost of the system and releases the men involved for other projects.

Question: How is Nalco Consulting Service useful to an existing plant for which no immediate expansion is planned?

Answer: Few plants require or can afford a *full-time* water conditioning engineer – yet *all* plants find at times that they need the services of such an engineer. Nalco meets this need by supplying plant operators with the assistance they need, when they need it, to an extent determined by mutual agreement. Consulting service prevents many problems before they occur by anticipating the need for changes in chemical treatment control and application—giving you maximum benefit from every dollar spent on water treatment chemicals.

Question: Isn't consulting service usually supplied, free of charge, with the purchase of water treatment chemicals?

Answer: *Product application assistance* is offered for specific chemicals. Consulting provides an overall *program.* The complexity of many of today's systems requires attention to all phases of operations. While product application assistance is an important Nalco service to industry, often it should be supplemented with a consulting arrangement which provides the intensive and effective integration of *all* water treatment into a successful program.



Selden K. Adkins, Manager, Nalco Consulting Service Department

Question: What do you mean when you say "the highly specialized nature" of chemical engineering as applied to water conditioning?

Answer: No one engineer can know every single detail that is important in each phase of an overall water treatment program. Coagulation, filtration, stabilization, softening, sludge conditioning, ion exchange, slime and microbiological control—all these and many more must be considered. Nalco's coagulation, stabilization, power industry chemicals, process antifoams, cooling water, and microbiology departments maintain an effective working knowledge of each of these special areas of water treatment. Each department manager is an expert in his given field, and is assisted by an average of 25 staff and laboratory personnel. Nalco's Consulting Department draws on the specialized knowledge of each of these groups to provide the engineering knowledge needed in each plant. By coordinating the efforts of all these specialists and utilizing the knowledge and experience of our national field force, Nalco can provide precise information to get successful results. That so many departments are vital in our operations indicates the degree of specialization necessary.

Question: How can a company that sells chemicals be a "true" or impartial consultant?

Answer: Regardless of affiliation, consultants are responsible for producing effective results. Nalco consultants have nothing to gain—and everything to lose—by recommending any chemical or method not in the best interest of the client. Water treatment products offered by Nalco (or any reputable company of this type) are usually special blends, each designed to do a specific job under a specific set of conditions. These specialized products would not exist if there was an *exact* equivalent "open market" chemical available. The Nalco Consulting Department recommends the most suitable chemical for a given situation—regardless of whether or not it is a Nalco product. The single objective of Nalco Consulting Service is to provide the client with maximum treatment efficiency, regardless of which chemical or equipment is used. Chemicals are no more than tools to the consulting engineer—what he provides are programs, methods, and results.

Suggestion: Write or ask your Nalco Field Representative for information on how Nalco Consulting Service can be of help in *your* water treatment program.

NALCO CHEMICAL COMPANY

6234 West 66th Place • Chicago 38, Illinois

Subsidiaries in England, Italy, Mexico, Spain, Venezuela and West Germany

In Canada: Alchem Limited, Burlington, Ontario

Nalco® . . . **Serving Industry through Practical Applied Science**

Proved 10,000 times the world over

Fig. 16031—New, steel pressure seal "Y" globe valve for 600 pounds.

Fig. 11365—Steel pressure seal horizontal lift check valve for 1500 pounds. Piston guided disc.

Fig. 19003—Steel pressure seal gate valve for 900 pounds.

Powell . . . world's largest family of valves

More than 10,000 Powell Steel Pressure Seal Valves are now in use all over the world—indisputable evidence they are meeting the challenge of modern industry to control constantly higher pressures at elevated temperatures.
These quality, precision-built, precision tested, leak-proof valves, with exclusive features of design and construction, are available in gate, globe, angle, check patterns for 600 to 2500 W.P. and special working pressures. Many are in stock for quick delivery. Contact your nearby Powell distributor—or write directly to us.

THE WM. POWELL COMPANY • DEPENDABLE VALVES SINCE 1846 • CINCINNATI 22, OHIO

REDISCOV

A modern boiler room in pastel colors has a clean, almost clinical appearance. Automatic sealed handling of coal and ash eliminates dust. Advance-design combustion equipment gets top BTU's from your fuel dollar.

ER COAL !

COAL IS CLEAN because of advanced techniques in processing and combustion

The clean handling, clean burning characteristics of coal brought about by technological advances in preparation and combustion equipment, have made it an even stronger logical choice for low-cost, efficient fuel.

To provide a cleaner, more uniform product, the progressive coal mining industry has developed and installed radically new techniques in mining and preparation. More are on the way, too, as new mines become truly push-button mechanized.

Phenomenal, too, are the strides made in handling and combustion equipment. Sealed conveyor systems, dustless operation, fly ash reinjection, hydraulic ash carriers, electrostatic precipitators, and other innovations give coal a *clean* bill of health.

Through low-cost and high efficiency, coal provides more energy for your fuel dollar. Chesapeake and Ohio transports it economically from the world's finest bituminous coal reserves. Coal is the one fuel that will be available for centuries.

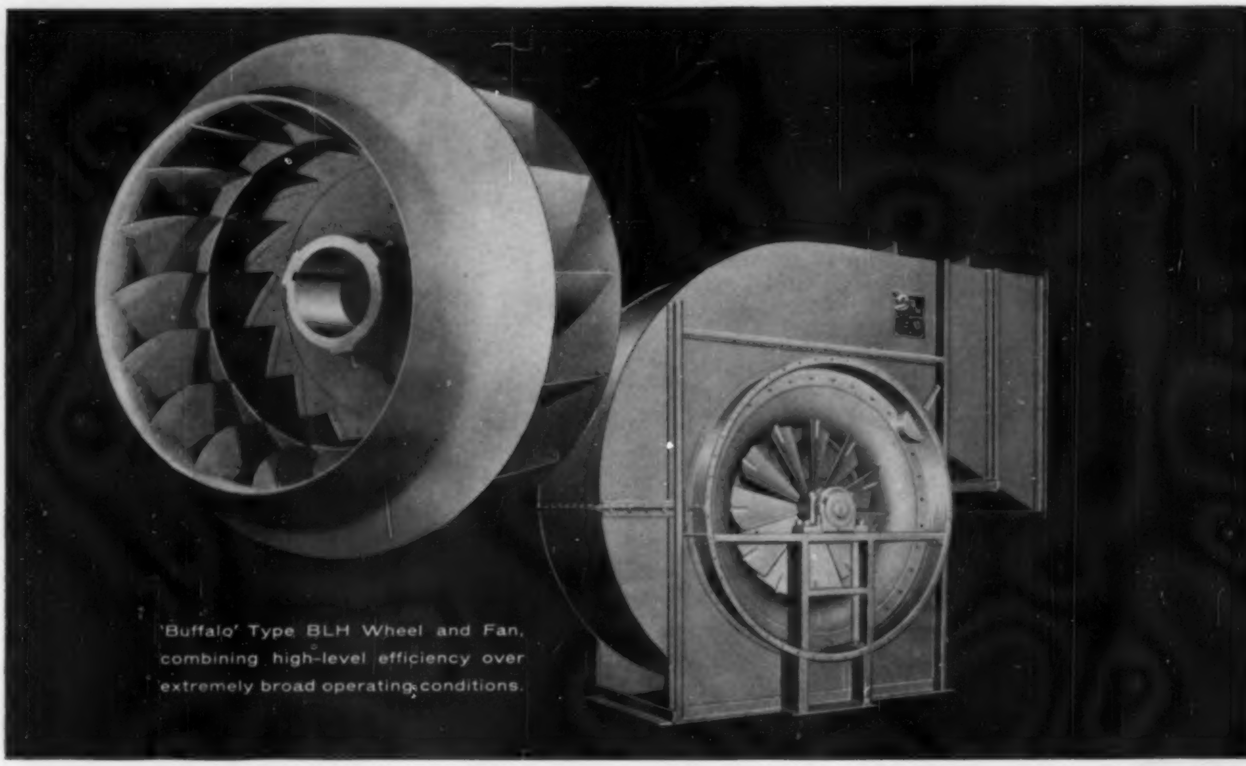
Chesapeake and Ohio Railway
TERMINAL TOWER, CLEVELAND 1, OHIO
Outstandability in Transportation

Coal is a good neighbor because of developments in modern equipment that offer stoker-to-stack cleanliness. Textile plants, laundries, hospitals now avail themselves of this reliable, efficient and convenient fuel.

C&O Fuel Service Engineers provide free consultation to C&O patrons on combustion, application, equipment, or plant arrangement problems. Write to R. C. Riedinger, General Coal Traffic Manager, above address.

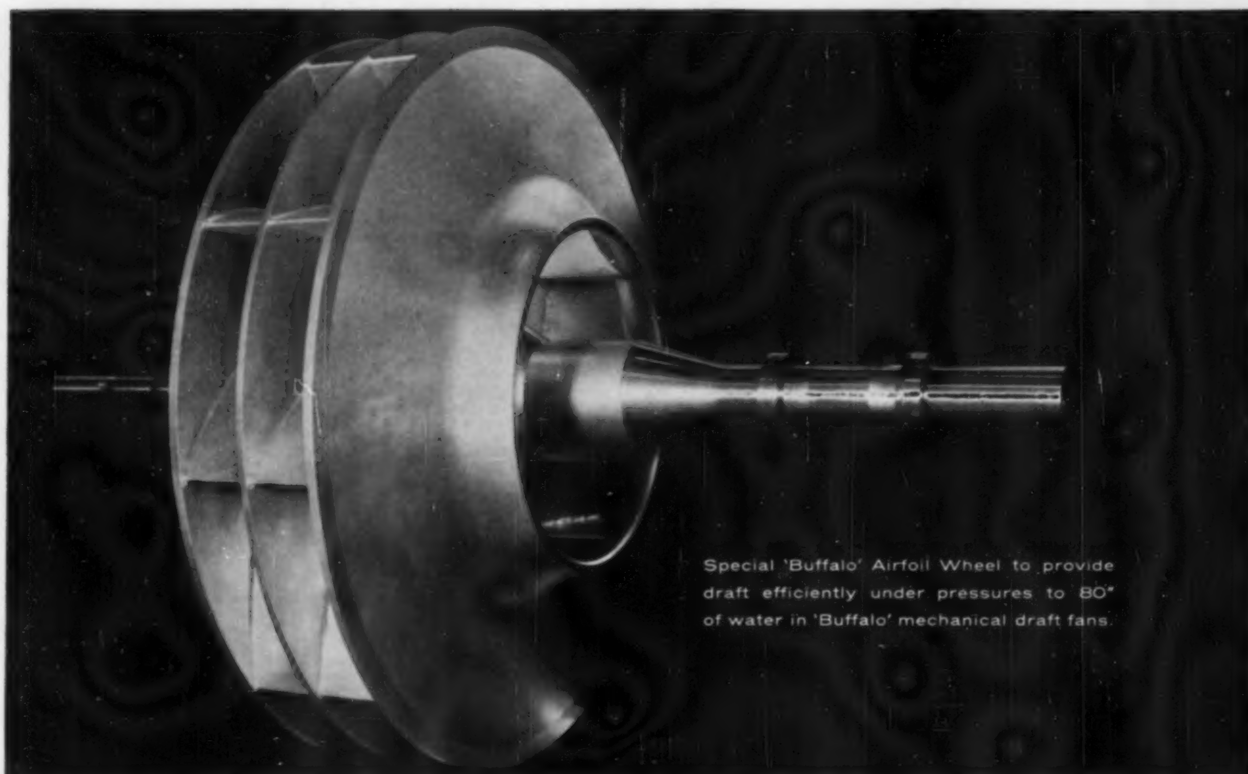
The 5,100-mile Chessie Route directly serves over 300 mines in America's richest bituminous coal reservoir with the finest fleet of 68,000 coal cars. Specify C&O routing for dependable, efficient delivery.

CHESSIE SERVES THE COAL BIN OF THE WORLD

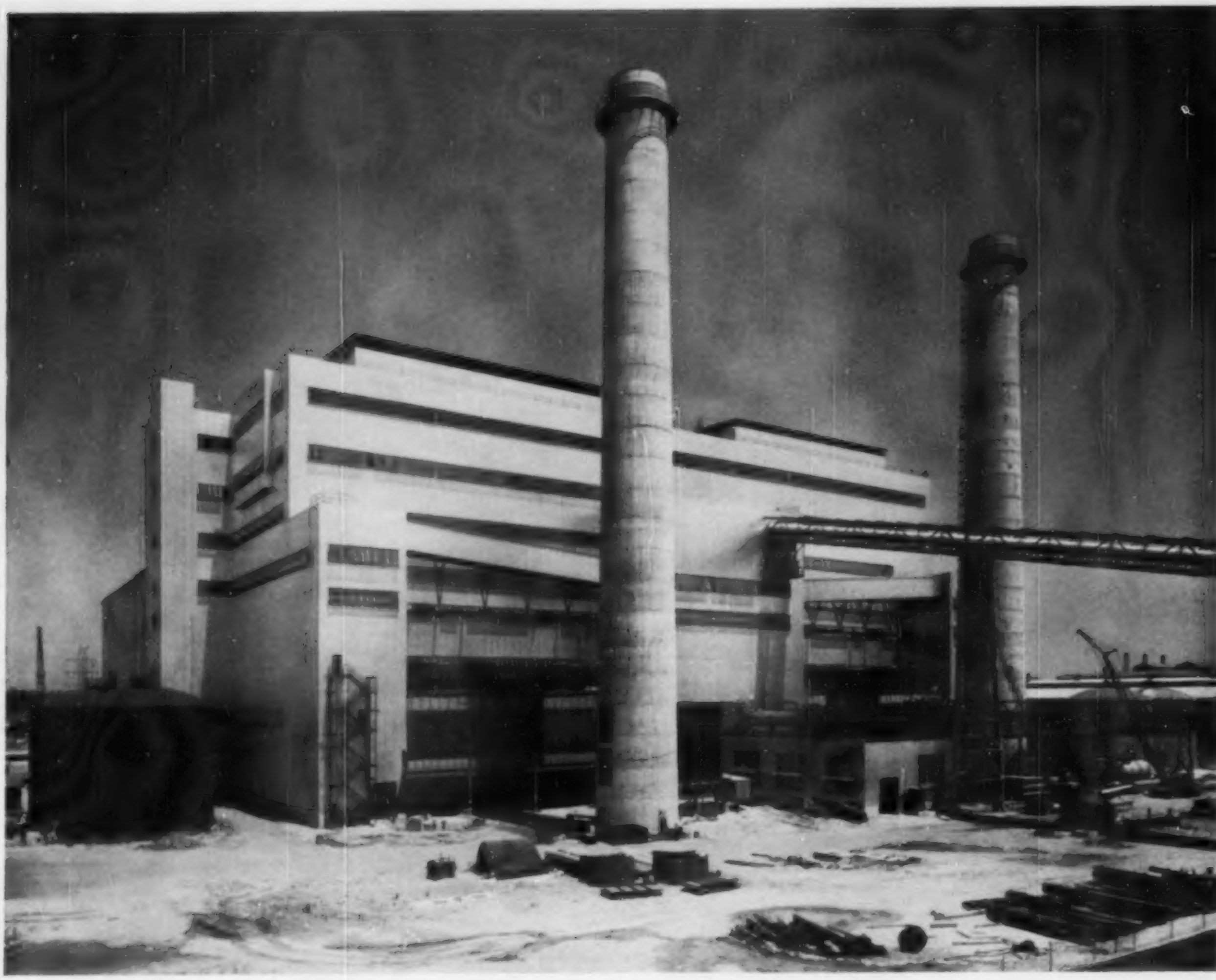


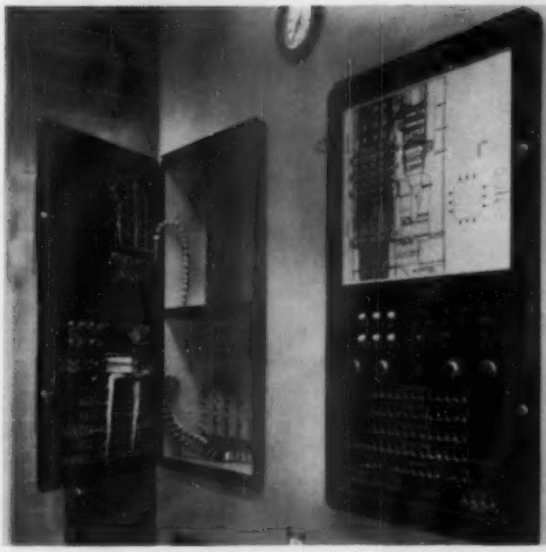
'Buffalo' Type BLH Wheel and Fan, combining high-level efficiency over extremely broad operating conditions.

WHAT ARE



Special 'Buffalo' Airfoil Wheel to provide draft efficiently under pressures to 80" of water in 'Buffalo' mechanical draft fans.

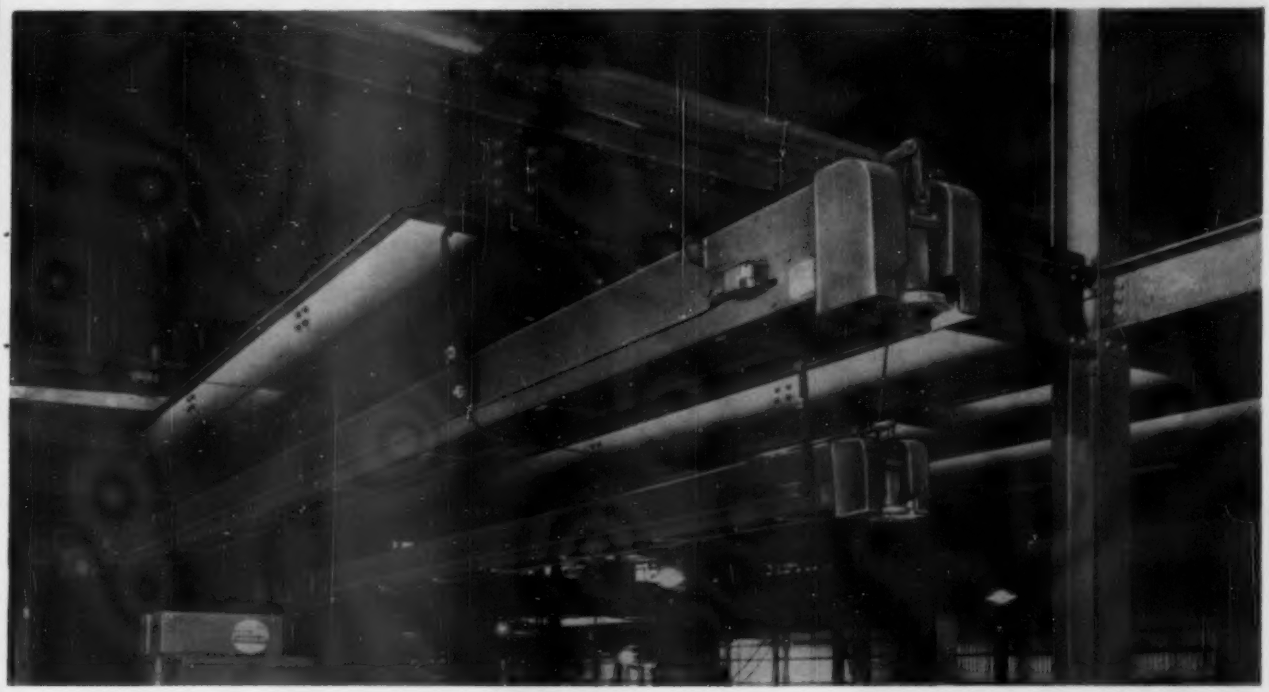




Panel provides centralized control of soot blowing at Eddystone. With the Vulcan SSC-120 Selective-Sequence controller, each blower can be operated four times during a schedule, or there can be four different schedules. The sequence can be varied by means of a jack board. Any soot blower can be operated at any point in the sequence by plugging one end of a patch cord into the blower jack, and the other end into the desired sequence jack. Write for Bulletin 1029.

Wall deslagger conserves steam generated at Eddystone by three special package boilers. High striking power of Vulcan RW-3E drives off gummy masses to assure high heat-transfer capacity, and uniform superheat and reheat temperature control. Dual motors are used: one speeds the nozzle to and from the blowing position, the other rotates it slowly for thorough cleaning. All parts are covered for protection, assuring long life with low maintenance. Write for Bulletin 1034.

Vulcan T-30's have 30- and 37-foot travels. *Motors are mounted at the boiler end to facilitate maintenance, yet away from heat of the boiler wall. Their placement avoids interferences. Write for Bulletin 1030.*



For cooling water systems, the latest word is ENDCOR

ENDCOR – new from Dearborn's research laboratories, gives better corrosion control at lower cost in open recirculating cooling water systems.

ENDCOR – promotes rapid film formation . . . is completely stable against oxidizing agents.

ENDCOR – sharply reduces corrosion rates and deposit formations . . . minimizes sludge adherence to heat exchange surfaces.

ENDCOR – permits operating any open system at higher pH readings . . . saves on acid.

Developed after exhaustive experiments, ENDCOR has been incorporated in Dearborn's Polychrome® and non-chromate treatments and successfully tested under severest laboratory and operating conditions in customer plants for over a year. Available now in powder or briquette form. Your Dearborn engineer will be happy to fit these new treatments to the specific needs of your system. Call him today or write for detailed Technical Bulletin.

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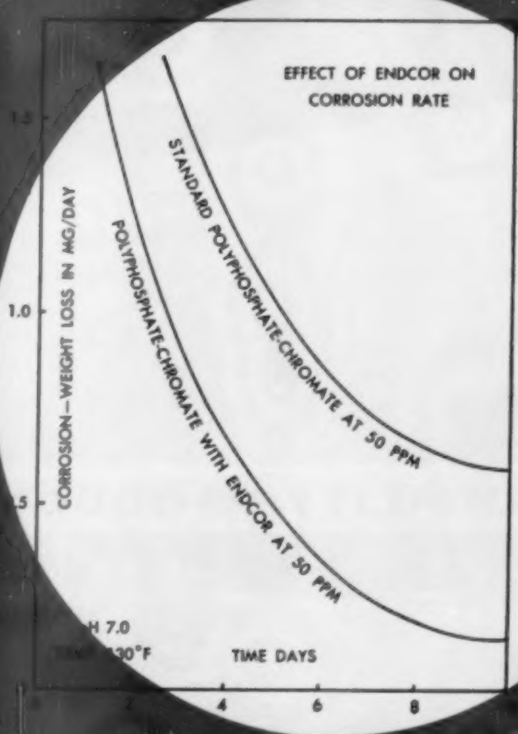
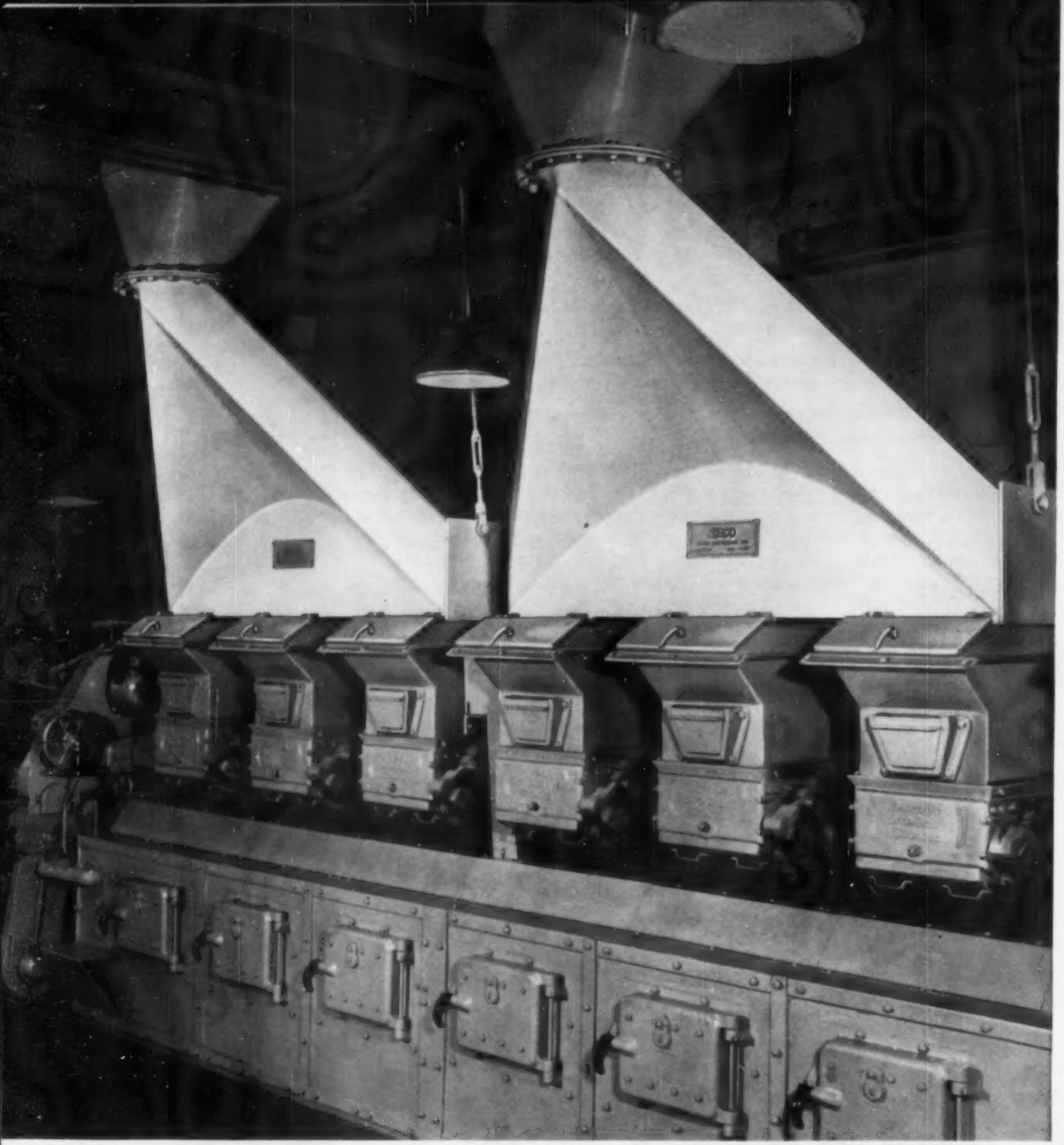
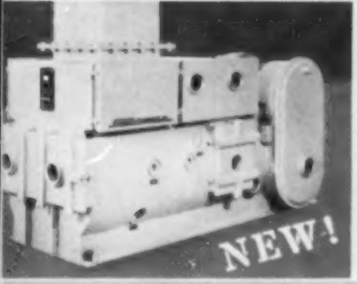


dearborn

pioneer in the science of corrosion control

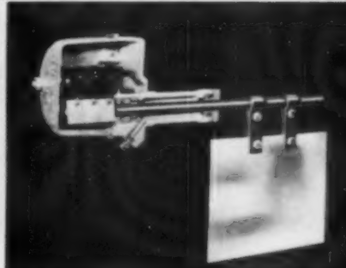


S-E-Co. QUALITY PRODUCTS



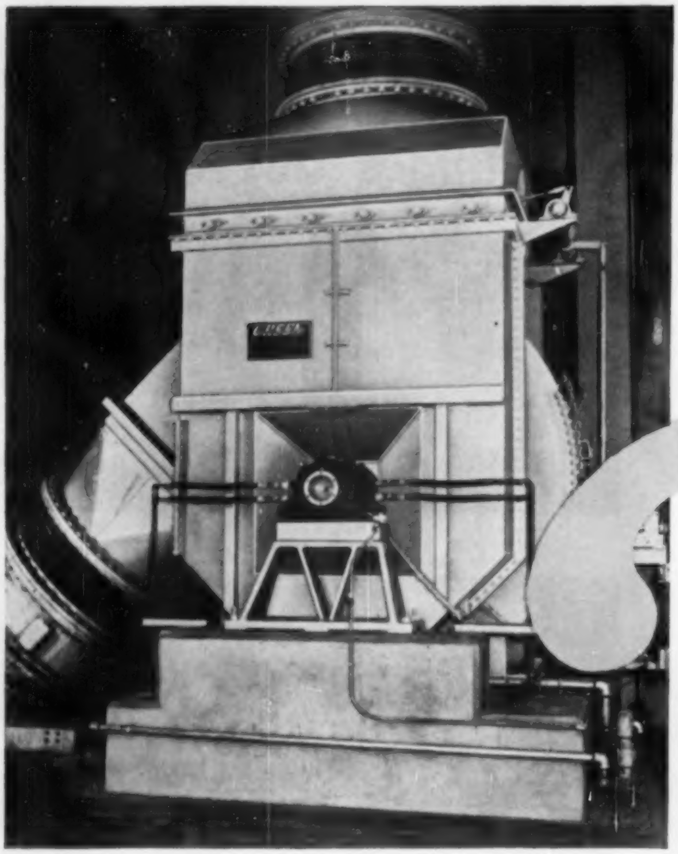
GRAVIMETRIC FEEDERS
Weigh and Feed

VOLUMETRIC FEEDERS
Feed Sticky Coals



STOPPAGE ALARMS
Two Types

One of Brookhaven's three Green induced draft fans. Each exhausts 109,000 CFM at 56" S.P. and 140° F., operating at 1775 RPM. Each rotor was successfully subjected to spin tests producing 50% greater than normal operating stress.



WHY DID BROOKHAVEN SWITCH TO GREEN HIGH PRESSURE FANS FOR ATOMIC PILE COOLING?

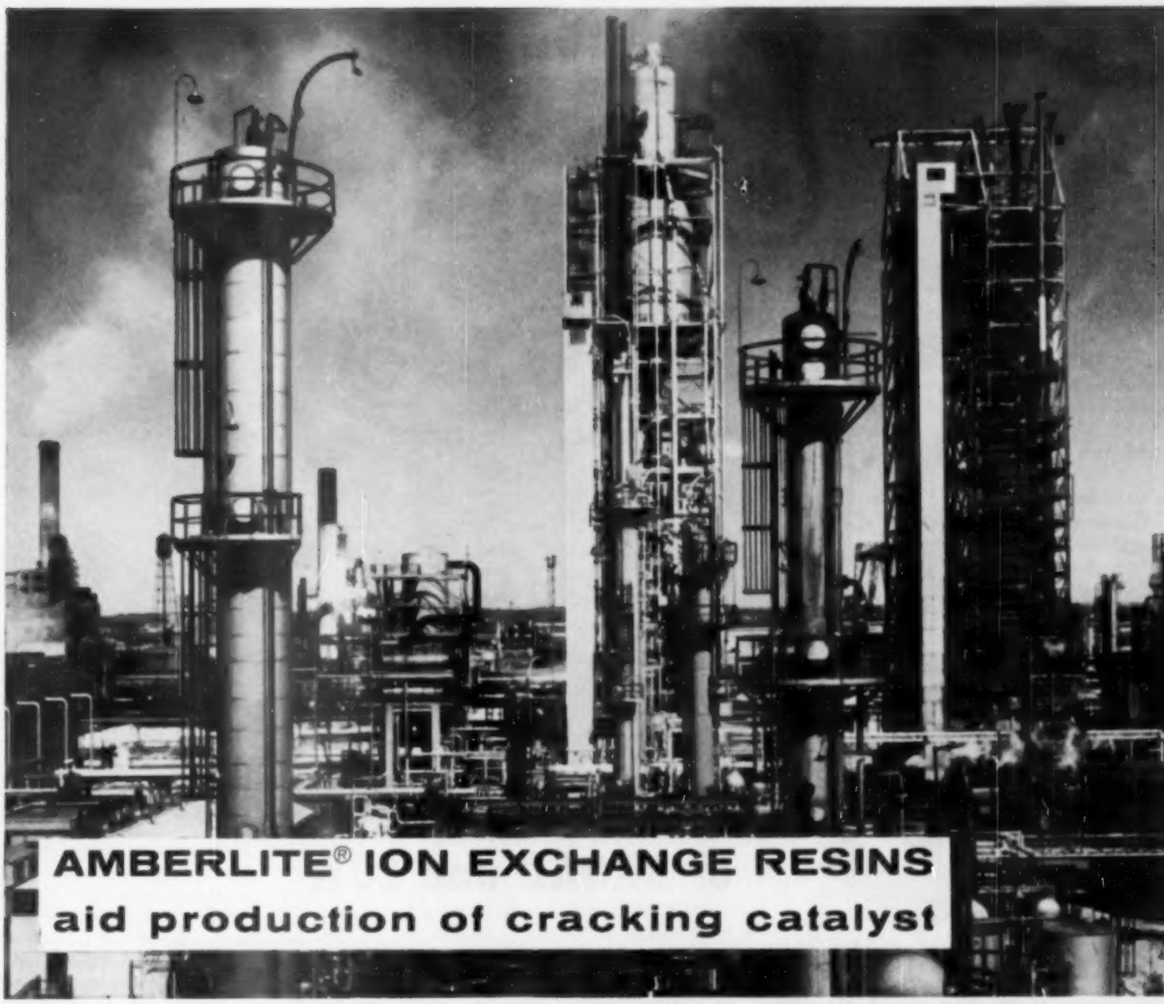
For 10 years, Brookhaven National Laboratory at Upton, N. Y. had used five fans of a leading make for exhausting the hot, slightly radioactive gases from its experimental atomic pile installation. These fans were still good, yet Brookhaven replaced them with three new Green units. Here's why:

Due to design changes in the atomic fuel, the air flow requirements changed considerably thereby making it economical to purchase new fans. This change in air flow requirements plus the new Green fans with their forged and machined rotors and efficient airfoil design (smoother air flow, less turbulence, less shock or eddy loss) save a total of $15/hour in power consumption. Not only does the replacement installation pay for itself, it gives Brookhaven brand new equipment, the most modern of its kind, built to provide the reliability their atomic application absolutely demands.

It will pay you—as it did Brookhaven—to investigate the replacement of your present fan equipment with new high efficiency Green airfoil fans.

Green

THE GREEN FUEL ECONOMIZER CO., INC. BEACON 3, NEW YORK



Hall Industrial Water Report

VOLUME 8 NOVEMBER 1960 NUMBER 6

Pouring Oil on Water

Oil will quiet angry waters. But when oil is inadvertently introduced to boiler feedwater it can cause plenty of trouble with blistered tubes and carryover. Other contaminants in makeup water or condensate can be equally or even more dangerous. Thus, for good boiler operation it is essential to keep boiler feedwater free of significant quantities of contaminating materials.

It is part of the Hall engineer's job to help you locate possible sources of contamination before difficulty occurs. When, in spite of all precautions, something troublesome does get into the boiler feedwater, he is prepared by his training and experience to help you to locate the source quickly. He is also prepared to be of service on all your water problems whether they be in the boiler house, in process, in cooling systems or in waste disposal.

Silica Trouble

An unusual condition caused production losses in an Eastern paper mill. Makeup water for the high-pressure boiler was clarified with aluminum sulfate and activated silica and then deionized. When upsets occurred in the clarifier, colloidal silica passed through the deionizer and into the boiler. This resulted in high boiler water silica concentration, which necessitated boiler operation at lower than normal load. Hence, loss of production.

Hall engineers studied clarifier operation by means of numerous jar tests. These showed that substituting a non-siliceous Hagan coagulant aid for activated silica would produce satisfactorily clear water with complete elimination of silica carryover. A bonus was a more than twenty percent increase in anion exchanger capacity due to the decrease in the silica content of the clarified water.

Tracing Condensate Contamination

Foaming of the boiler water at a midwest manufacturing plant indicated that contamination of feedwater was occurring. A further indication of contamination was difficulty in testing—when an alkaline oxidizing reagent was added to samples for oxidation of organic matter in the phosphate test, the water turned black.

The condition in the phosphate test was checked by Hall field engineer Earl Hoehn. He discovered that he got the same black color when he added the reagent to some condensate samples. He then used this unusual but timely test to trace the contamination to its source. It turned out to be nickel plating and metal cleaning solutions, which were getting into the condensate through small leaks in the steam heating coils in the solution tanks. The reaction between the nickel and the alkaline oxidant was producing black nickelic hydroxide.

Boiler Cleaning Problem

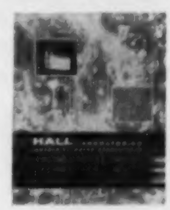
Many of the compressors and pumps in a New York State hospital are driven by reciprocating engines. The oily exhaust steam is used for space heating and heating hot water. The condensate is then returned to the boilers.

Because of the lack of oil removal equipment there is so much oil returned to the boilers at times that some can be seen floating on boiler water samples. Oily sludge accumulates and boiler cleaning is a real problem. A turbine quickly becomes fouled so badly it is valueless. The only effective procedure the operating men discovered was swabbing out the tubes with rags soaked in a solvent.

When Hall field engineer Sam Dilcer learned about the problem he tried boiling out the boilers with a strongly alkaline metaphosphate-metasilicate (Calgonite) solution. This is usually effective but in this case the amount of oil in the sludge deposits was so great the boilers remained dirty. Wire brushing was necessary and the wire brushes became fouled so rapidly they had to be rinsed in a solvent after passing through one tube.

Dilcer then recommended boiling out with Calgonite plus a cleaner of the emulsified hydrocarbon type (Calgon Emulsion Cleaner). This left nothing to be desired. Wire brushes drawn through the tubes remained clean. The plant engineer told Dilcer, "You licked our problem with the boilers so we'll have to find something else to keep you busy."

New Booklet Available



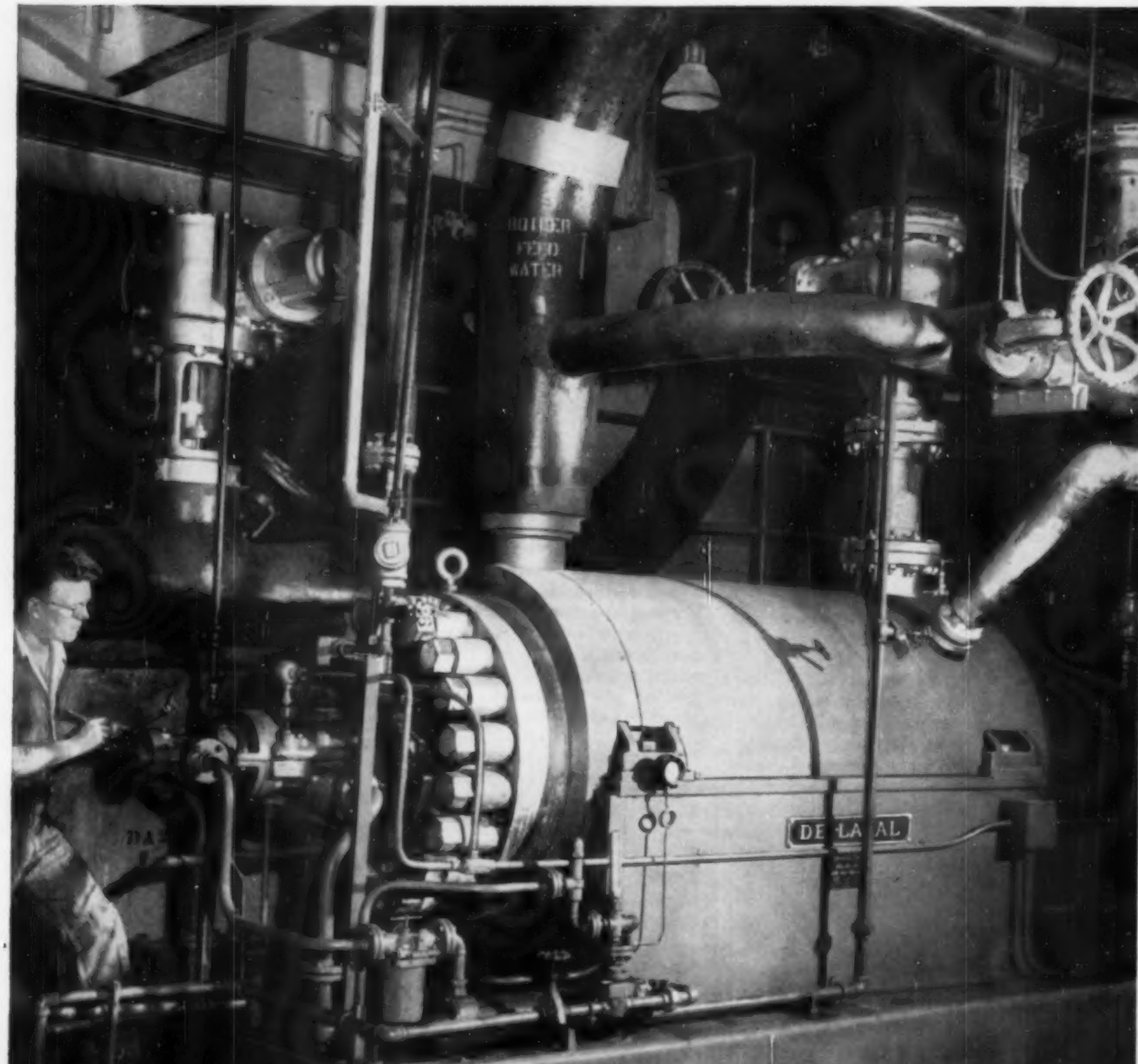
A new 24-page booklet describes the many ways industry can use Hall Laboratories industrial water consulting services.

For your copy, write on your letterhead to:

HALL LABORATORIES
HAGAN CENTER, PITTSBURGH 30, PA.
Consultants on Procurement, Treatment, Use and Disposal of Industrial Water

DIVISION OF **HAGAN** CHEMICALS & CONTROLS, INC.

DE LAVAL Feed Pumps serve



latest unit at Central Hudson

Burns and Roe Inc., Engineers and Constructors, complete third unit at Danskammer Station

To meet increased load demand, Central Hudson Gas & Electric Corporation has added a 140,000 KW 2400 psig main unit at its modern Danskammer Steam Station. Providing dependable boiler feed service are two 2500 HP direct motor driven half capacity De Laval barrel type boiler feed pumps. The earlier units have De Laval full capacity variable speed boiler feed pumps.

← Each De Laval pump has intermediate pressure bleed off for use in controlling steam temperature from reheater.

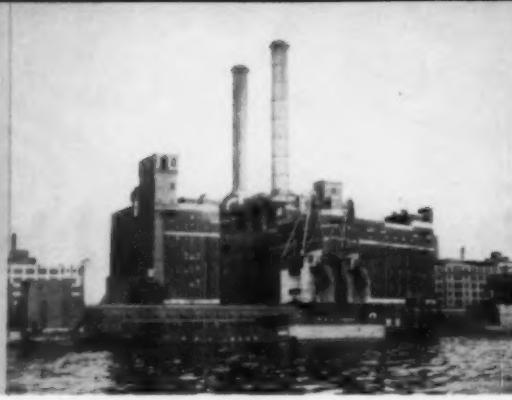
Central Hudson's modern Danskammer Steam Station located at Roseton, New York on the Hudson River. ↓

DE LAVAL STEAM TURBINE COMPANY
886 NOTTINGHAM WAY, TRENTON 2, N. J.

DL-210

FIRST

East River Station. One of the three huge C-E boilers completed in 1929 for Consolidated Edison Company of New York was the world's first boiler to produce a million pounds of steam per hour. To mark the unit's completion, a luncheon for 90 persons was served inside its furnace.



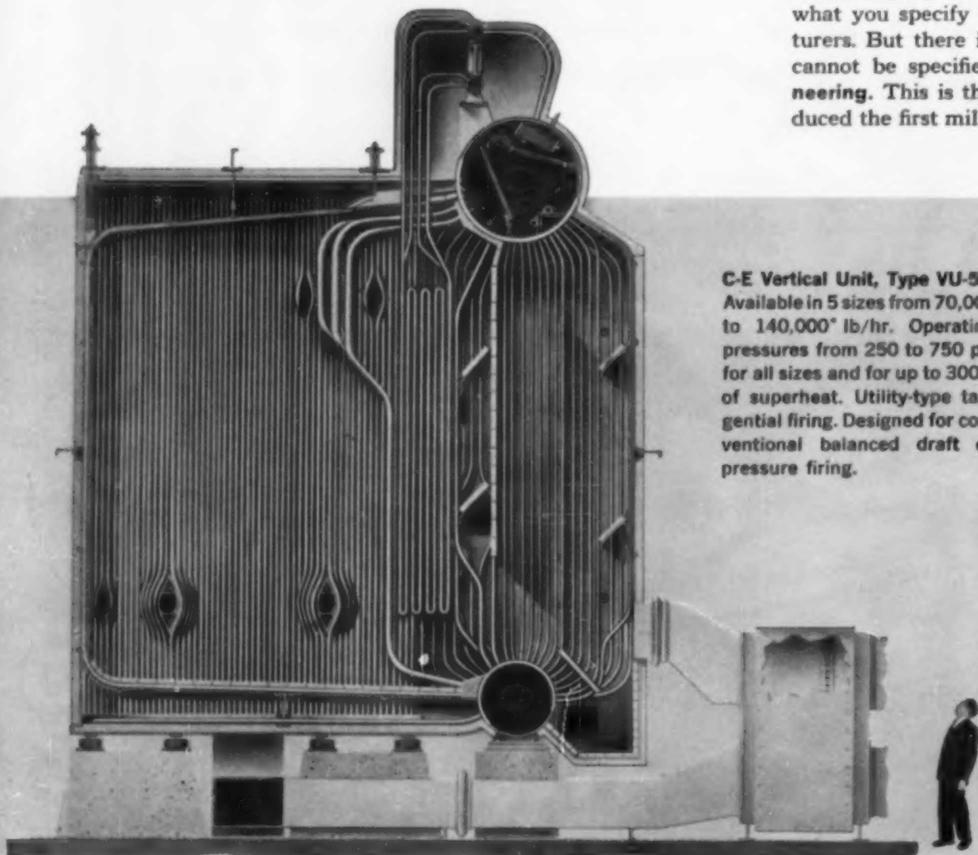
HIGHEST

Eddystone Station. World's highest-pressure utility boiler went into operation in 1959 at the Eddystone Station of Philadelphia Electric Company. This supercritical C-E unit serves a 325,000-kw turbine and is designed for an operating pressure of 5000 psi and temperature of 1200 F.

In C-E Industrial Boilers—

UTILITY-BOILER ENGINEERING

When buying industrial boilers, you can get what you specify from a number of manufacturers. But there is an intangible quality that cannot be specified: C-E's **utility-boiler engineering.** This is the engineering skill that produced the first million-pound-per-hour boiler in



C-E Vertical Unit, Type VU-55. Available in 5 sizes from 70,000 to 140,000* lb/hr. Operating pressures from 250 to 750 psi for all sizes and for up to 300 F of superheat. Utility-type tangential firing. Designed for conventional balanced draft or pressure firing.

C-E Vertical Unit, Type VU-10. Available in 9 sizes from 10,000 to 60,000 lb/hr. Operating pressures to 475 psi, superheat to 150 F in 20,000-60,000 range. Efficient over a wide range of output. Coal, oil or gas-fired.

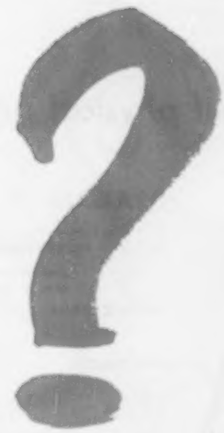
WRITE FOR CATALOGS

ALL TYPES OF STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT; NUCLEAR REACTORS; PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; SOIL PIPE

GUEST EDITORIAL

Plain Words

By CAPRICORN



Who is Capricorn?*

Complaints are fairly widespread that the number of conferences is growing and is getting beyond a joke. Conferences—and exhibitions (the two often go together)—multiply with the spawning of specialisms. Think of a good theme, a catchy title and you are half way to planning a profitable conference.

Don't try and do the whole thing yourself, though. Far better get hold of three or four experts who are capable of some deep thinking on the chosen subject and have a flair for high-level staff work. They must also have that curious weakness for attending committee meetings that is, I think, a form of vanity. Handle them carefully in the early stages, otherwise they may decide they can't afford the time and leave you high and dry. Once they get stuck into the job, however, keep them on their toes. Follow through, too, right at the end of the proceedings by writing each of them a real personal letter thanking him for his help.

If you can win the cooperation of a dozen or so people in this way you can adopt a crop-rotation system, letting each one lie fallow for a year or two, until such time as he is beginning to wonder why you have not been on to him lately. Just at that moment—when he is being gnawed by doubts as to his own ability—come in smoothly with your next request.

If you are an old conference hand you will know not to overestimate or underestimate the importance of the papers and addresses. They must be good enough to earn general approval from a critical audience, and to attract all the important people in your chosen field. But beyond that they are not important; their job is to generate a stimulating atmosphere so that the really fruitful contacts and discussions can develop. Then will you have earned your reward. Communication, the life blood of science and engineering, will flow freely and no man will be able to measure the manifold value of the conference.

When the summit conference broke down and Eisenhower and Khrushchev were glaring at each other across the world, and the newspaper headlines were given over to the trial of Powers, an American professor attending the First International Congress of the International Federation of Automatic Control in Moscow brought with him his wife and four children, and after the conference he took them on a holiday tour of Russia. This is one of many thousands of cases where men on the lower slopes of international contacts are quietly working away, exchanging ideas and information, while on the summit the spotlight of publicity singles out discord and disagreement.

So press on with your specialist conference. Ignore the folk who say there are too many (they don't have to attend if they don't want to). Put on a good show and there will be no shortage of delegates.

* Capricorn's column appears regularly in the pages of our contemporary *Engineering*, published in London, England. Diligent research has failed to uncover his identity and *Engineering*'s editor, F. B. Roberts, says ". . . he is an imaginary person who, I may say, is more successful than many of us who are real." Capricorn's whimsically pointed remarks continue to delight us—we think you'll enjoy him too.

Science Looks at

Combustion Mechanics in . . .

Effects of physical parameters:

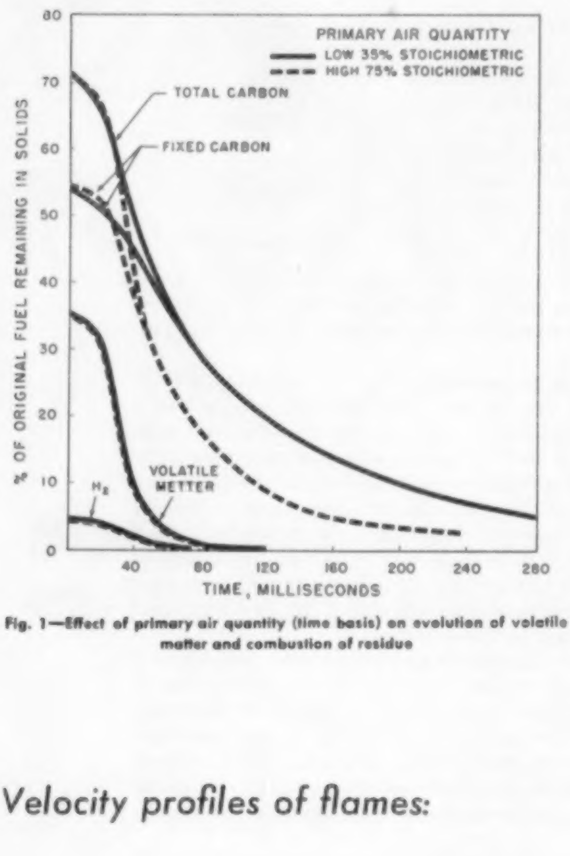


Fig. 1—Effect of primary air quantity (time basis) on evolution of volatile matter and combustion of residue

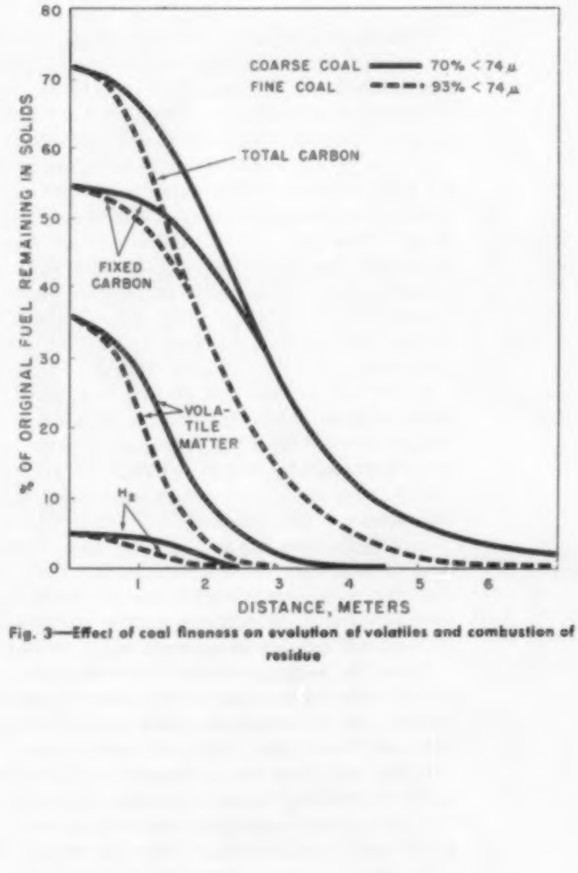


Fig. 3—Effect of coal fineness on evolution of volatiles and combustion of residue

Velocity profiles of flames:

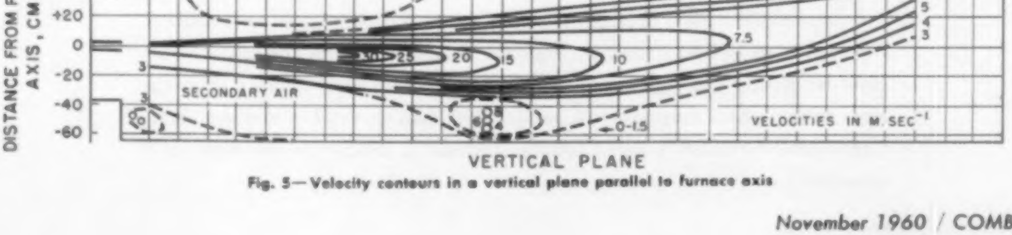


Fig. 5—Velocity contours in a vertical plane parallel to furnace axis

. . . First Performance Trial and First Combustion Mechanism Trial with Pulverized Coal*

Our recent experience at the Joint Solid Fuels Conference in Charleston, W. Va., showed the tremendous interest in and need for real knowledge of the basic mechanics of pulverized coal firing. We are faced with a choice between progress through a thorough understanding of how coal burns or mediocre advancement by continued application of empirical data. This British study shows how science is at long last investigating a subject that has been an art for too many years—the business of burning fuel. Sample curves on the opposite page give an idea of what can be accomplished.

By E. H. HUBBARD†

British Petroleum Co. Ltd.

OVER a period of 10 years both engineering and scientific experiments have been carried out by the International Flame Research Foundation using flames of gaseous and liquid fuels. The results of this work have enabled a comprehensive picture to be obtained of the turbulent jet diffusion flame, a flame which is much used in the metallurgical and ceramic industries.

The series of trials described in these papers were concerned with flames from a high-volatile pulverized coal projected centrally along the axis of a long narrow furnace and having the secondary air arriving through an annulus concentric with the primary. There is thus a certain aerodynamic likeness between these flames and the previous gas and oil flames studied.

In the Performance trial 16 flames were studied, the measurements inside the flames being confined to the flame axis. In the Combustion Mechanism trial only one flame was examined, but the internal measurements were made to give a three-dimensional picture.

Some of the results of the first Performance trial with pulverized coal have already been published (1, 2)[1] and only the broad conclusions are given here.

Plan of the Trials

Previous work (3) on oil and gas flames has indicated that most of the important flame properties can be related to the air/fuel mixing rate and that this is a function of the "equivalent nozzle diameter" of the burner.

It was therefore decided in this trial to keep a constant nozzle diameter for the primary air and coal and to use two levels of primary-air quantity. The constant nozzle diameter means, in the case of a slow moving secondary-air stream, that the rate of mixing between the primary fluid (air plus coal) and its surroundings should be constant with distance until the combined jet is affected by the walls of the enclosure.

To determine the influence of the secondary air on the mixing between the two streams, each of the above two conditions were combined in turn with two concentric secondary-air ports giving (*a*) a very low and (*b*) a high secondary-air velocity. Each of these four conditions of mixing was studied with two levels of fineness (70 and 93 per cent through 74 μ and with and without water-cooling pipes in the furnace. The number of pipes used was the maximum possible consistent with flame stability, the pipes being evenly spaced along the furnace walls except for the first two metres.

Table I gives the plan of experiments and the input variables and Table II gives the coal analysis.

The furnace pressure, which has a very great effect on the general temperature level, was adjusted so that the oxygen content in the chimney corresponded to the measured 110 per cent stoichiometric air of the input variables. It has been shown in previous experiments (4) that this condition gives a zero static pressure within the furnace doors at burner height and that the inleaking air here is negligible.

Supplementary Experiment

In the main experiment the effect of secondary air velocity was not significant and this was considered to be because the primary air quantity was too high.

It was impossible at that time to reduce the amount of air with the existing installation, but by doubling the coal rate it was possible to use the same absolute amount of air which then became only half the previous value when expressed on a stoichiometric basis. This supplementary experiment was conducted with the following variables.

* Published in the August 1960 issue of the Journal of the Insitute of Fuel, 18 Devonshire St., London, W. 1.

† Formerly principal investigatior, International Flame Research Foundation.

[1] Numbers in parentheses refer to similarly numbered items appearing in the References at the end of the article.

(*a*) Coal rate constant at 350 kg h^{-1}.
(*b*) Total air constant at 110 per cent stoichiometric.
(*c*) Water cooling as used in the main experiment. This was necessary to avoid damage to the furnace.
(*d*) Coal fineness. 70 per cent through 74 μ.
(*e*) Burner sizes, as for the main experiment.
(*f*) Primary air 35, 25 and 17 per cent of stoichiometric.

TABLE I—PLAN OF INPUT VARIABLES FOR THE PERFORMANCE TRIAL

Primary Air Quantity Percentage Stoichiometric	Primary Air Velocity M/Sec	Secondary Air Quantity Percentage Stoichiometric	Secondary Air Velocity M/Sec	Fineness Percentage <74μ	Water Cooling
35	19.8	75	1.5	70	No
					Yes
				93	No
					Yes
75	40.4	35	0.7	70	No
					Yes
				93	No
					Yes
35	19.8	75	71.0	70	No
					Yes
				93	No
					Yes
75	40.4	35	34.2	70	No
					Yes
				93	No
					Yes

Coal rate, 170 kg/h (1.15 × 10^6 kcal/h); primary-air temperature, 80 C; secondary-air temperature, 400 C; total air, 110 per cent stoichiometric; primary-air diameter, 100 mm; secondary-air annulus, (*a*) 760–176 mm; (*b*) 205–176 mm.

Measurements Made During The Performance Trials

During these trials measurements of gas velocity, temperature and composition, and solid particle concentration and composition were made on the flame axis only. External measurements of the narrow angle flame radiation and emissivity were made using the modified Schmidt method and the wall temperatures, as determined by the use of thermocouples embedded in the hot face, were recorded. The instrumentation and methods used are described in an internal report to be published shortly (5).

Results

It has been shown by many workers that the combustion of coal can be divided into two parts:

(*a*) *The evolution and combustion of the volatiles.*

When the volatiles are evolved, it is possible that cracking and soot formation will occur if there is insufficient air available to burn them. This soot formation can be prevented by having sufficient air to burn the

TABLE II.—ANALYSIS OF RAW COAL AND AN EXAMPLE OF THE ANALYSIS OF PULVERIZED COAL

	As Received	Dry Ash Free									
	Moisture	Ash	V.m.	Fixed Carbon	C.v. cal/g	C	H	O	N	S	Swelling No.
Raw coal (*a*)	10.1	9.1	40.5	59.5	7490	78.0	5.3	14.7	1.8	0.9	1/2
P.F. (*b*)	3.9	9.3	38.5	61.5	7786	79.5	5.0	13.5	1.0	1.0	
P.F. (*c*)	3.1	9.3	38.7	61.3	7727	78.9	5.0	14.2	1.0	1.0	

(*a*) Analysis carried out by Staatsmijnen, Limburg, to Dutch Standards.
(*b*) Analysis carried out by United Analysts, Newcastle, to B.S.S. 1016.
(*c*) Analysis carried out by United Analysts, Newcastle, by microanalysis methods used for the samples taken from the flame.

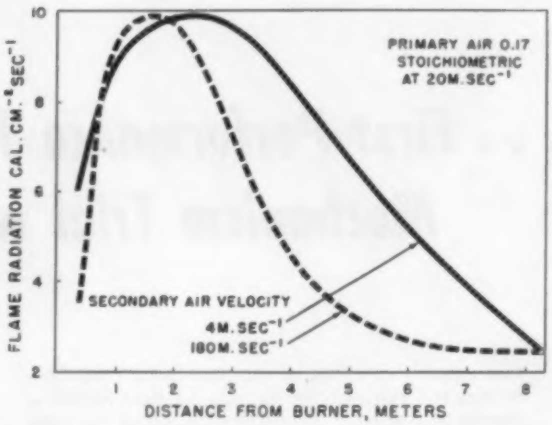


Fig. 2—Effect of secondary air velocity on flame radiation when the primary air quantity is low

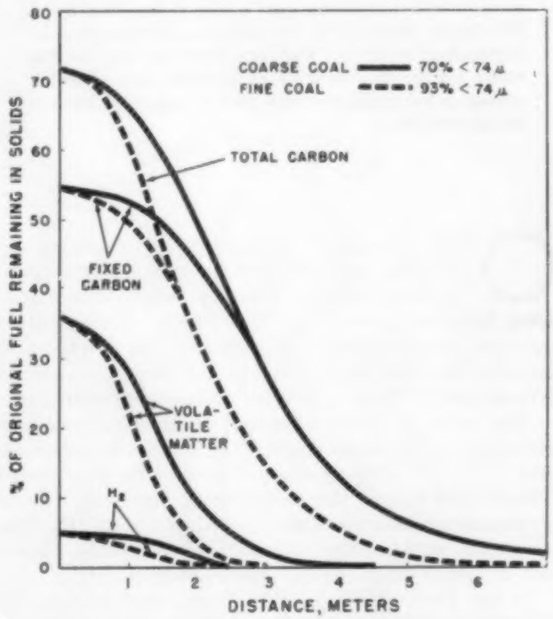


Fig. 3—Effect of coal fineness on evolution of volatiles and combustion of residue

volatiles as they are evolved. It may also be reduced under certain conditions by various gases, most of which are present in combustion products (6, 7).

(*b*) *Combustion of the coke-like residue.*

After the evolution of the volatiles the residue is surrounded by a cloud of volatile matter. This volatile matter burns and fresh supplies of oxygen must diffuse through it and the products of combustion before the combustion of the coke-like residue can begin.

The amount of solid material in a pulverized-fuel flame is very high, even after combustion is complete, because of the remaining ash. This means that the emissivity is high and that any changes in it due to different combustion conditions are small. The main effects on the flame of external variables are thus on the flame temperature, rate of evolution and combustion of the volatiles, and the rate of combustion of the residue.

Effect of Primary-Air Quantity (Primary Mixing). When the primary air quantity is very high the volatiles burn as soon as they are evolved and the combustion of the coke residue begins sooner. It is then not possible on this scale to differentiate the two stages by the temperature or radiation measurements. A decrease in the amount of primary air causes slower combustion of the residue (see Fig. 1 page 32) and it is then possible to observe that the gas temperature on the flame axis does not have a sharp peaked maximum, but consists of a flat topped curve which sometimes may even show a small drop in temperature between the volatile burning and the combustion of the residue. Fig. 1 is based on the analyses of the solids on the flame axis. It does not give the amount of volatile matter that has burnt, but the amount which has been evolved. In this instance, with hot refractory walls near the burner, this is only a question of heat transfer and not of primary air quantity.

Further reduction in the amount of primary air reduces the rate of combustion of the volatile matter on the flame axis as is indicated by the larger concentrations of unburnt gases. The narrow angle flame radiation however is increased owing to the higher temperature with less diluting air. The supplementary experiment showed that with further reductions in primary air quantity, the peak radiation passed through a maximum and then fell, possibly due to delayed combustion.

These results suggest that the energy emitted by the flame is more concerned with what is happening in the hot burning sheath than with the combustion processes on the flame axis.

Effect of Secondary Air Velocity (Secondary Mixing). The results of aerodynamic model work (8) show that the mixing of primary fluid with its surroundings is not affected by the momentum of the secondary air, provided that the secondary velocity is negligible. When this velocity is high, however, the mixing between the two streams is quicker than that expected due to the primary momentum alone.

In the main experiment in the furnace, the secondary air velocities were changed from 1 m s^{-1} to 70 m s^{-1}, but the results of the combustion, radiation and wall temperatures show very strikingly that this change had no effect when the primary-air quantity was 75 per cent stoichiometric and only a small effect when the primary air quantity was 35 per cent stoichiometric. This is because there was always a sufficient quantity of primary air available and the secondary mixing was therefore unimportant.

When there is not sufficient primary air, it is the cumulative effect of the two air streams which is important; i.e., the rate of mixing between coal and total air. When only 17 per cent stoichiometric of primary air was used, the radiation fell from the peak value after 2.6 metres from the burner when the secondary air velocity was low. When the secondary velocity was high, however, the cooling effect of the extra air reduced this peak radiation after 1.8 meters (see Fig. 2).

Effect of Fineness. When the size of the coal particles is smaller, the volatiles will be evolved more quickly (see Fig. 3) and, if there is sufficient oxygen available, the combustion and temperature rise of these and of the residue will be quicker. In this case the axial gas temperature was 140 C higher and the position of the maximum was nearer to the burner. Fig. 3 also shows the concentration of residual solid particles to be much less with the fine coal. The emissivity is slightly more with fine coal owing to the greater surface area. The flame and wall radiations are increased 25 and 8 per cent respectively at the maximum point which is moved 50 per cent nearer to the burner.

Effect of Water Cooling. The use of water-cooled pipes for the whole length of the furnace except for the first 2 meters absorbs 40 per cent of the heat input and reduces the heat lost through the water-cooled doors from 13 to 7 per cent.

The effect on the flame is to reduce the initial rate of combustion. There is more solid material in a water-cooled flame, the rate of initial temperature rise is decreased and the general level of temperature is reduced by 200 to 400 C. The flame radiation to a cold receiver is reduced by 40 per cent and the wall radiation is reduced by 50 per cent.

General Conclusions from the First Performance Trial

(*a*) In general the emissivity of these pulverized-coal flames is over 0.8 and remains over 0.7 when combustion is complete because of the ash content of the flame. Hence the variations in emissivity between one flame and another are not very great, although those flames which evolve the volatiles more rapidly in a proportion of primary air insufficient to burn them gave a slightly higher initial emissivity because of soot formation.

(*b*) The main effects of the variables are upon the rate of evolution and combustion of the volatiles, the combustion of the residual carbon and upon the radiant temperature of the flame. Primary air quantity is again the most important variable and fineness of coal the next most important.

(*c*) The measurements of temperature, velocity, gas and solid compositions were made only on the flame axis, and these results cannot always be related to the external flame radiation, which latter is derived from the outer burning sheath. This suggested that a full three-dimensional investigation would be useful in producing a picture of what happens inside a pulverized-fuel flame.

Objects of the Combustion Mechanism Trial

The main object of the Combustion Mechanism trial was to obtain a three-dimensional picture of what a pulverized-fuel flame looks like. Aerodynamically, the flame examined was the simplest two-stream two-phase system that could be produced with the existing equipment.

As a result of the trial it was evident that two aspects of flame structure required investigation. These were:

(*a*) Differences between mixing and combustion processes on the jet axis and those occurring in the outer sheath of intense combustion.

(*b*) Differences between the behaviour of the solid particles and the gases associated with them.

Preliminary Experiments

Several levels of primary air quantity (between 13 and 50 per cent stoichiometric) were tried with a high-volatile Lorraine coal. In each case the velocity of the primary air was maintained constant at 34 m s^{-1} by changing the primary burner diameter. The velocity of the secondary air was small (<1 m s^{-1}). The flame radiation was

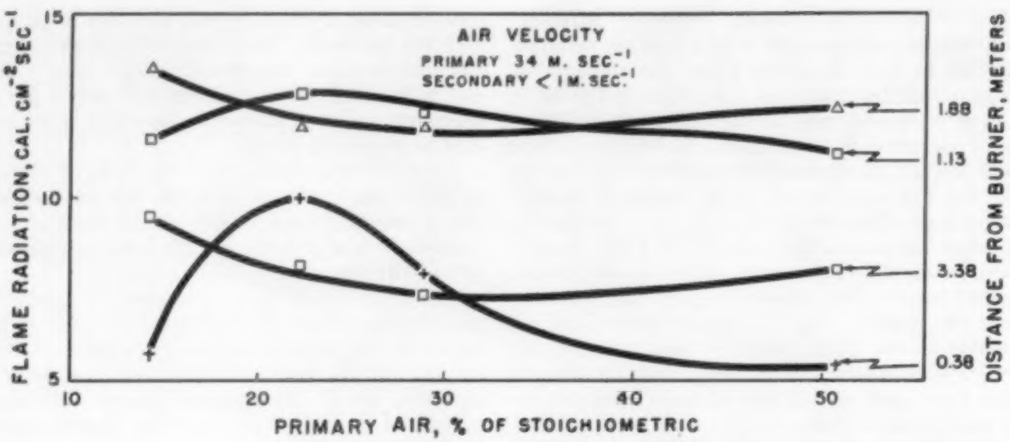


Fig. 4—Effect of quantity of primary air on flame radiation

measured in each case (see Fig. 4) and it was observed that the only large difference due to changing the primary air quantity was near to the burner. The significance is at the 5 per cent level, between 13 and 22 per cent and 22 and 28 per cent primary air, at 38 cm from the burner. None of the other differences are significant. The emissivity of a flame especially in this region approaches unity, and is not changed much by alterations of the input conditions so that any change in flame radiation is due to flame temperature change.

The explanation of this figure is that during the combustion of the volatile matter in the initial stages of the flame, any excess of primary air above a certain amount will act only as a diluent and lower the temperature. If the primary air is reduced, the temperature and hence the flame radiation rises. Reduction of primary air beyond a certain point, however, delays the combustion of the volatile matter and so the flame temperature does not develop as quickly. This suggests that there may be an optimum value of the primary air for high initial temperature. This value is 22 to 24 per cent stoichiometric for this coal, and represents about 50 per cent of the air required to burn the volatile matter only.

The phenomena discussed here apply chiefly to the outer burning sheath and it is of course the total air with which the fuel is associated that is important. In this particular experiment the velocity of the secondary air was negligible. If the experiment were repeated with a higher secondary air velocity which itself contributed to the energy of mixing, the same types of curve would probably be obtained with the maximum at a different level of primary air.

It seems likely that when the combustion of the volatile matter is delayed by lack of air, it will crack to form soot and hence a flame of this type has great value in understanding that combustion mechanism.

From a practical point of view the flame chosen for this experiment had as low a quantity and velocity of primary air as was practicable. Combustion of volatile matter thus occupied a long distance and a good opportunity was provided for making measurements.

Special Measurements

The internal and external measurements mentioned by Thurlow (9) were made during these trials, and in addition two special investigations were attempted.

Use of a Radioactive Tracer to Determine Mixing Patterns. In previous work on gas and oil flames the air:fuel ratio within the combustion chamber has been calculated from equations based on balances of the chemical elements involved. It is of course assumed in making a balance that the individual chemical elements used in the gaseous phase, together with those fractions of them which exist in the solid or liquid phases and which have originated from the fuel, have all arrived at the unit volume under consideration by the same path. This includes material which has recirculated.

In the case of pulverized-coal flames where the particles are much larger than in liquid-fuel flames, this may not be the case, and if it is not the case then a chemical balance cannot be made.

The aerodynamic mixing in the furnace between primary and secondary air streams was therefore measured for three vertical traverses by injecting a radioactive tracer into the primary stream and estimating its concentration at various points within the flame (10). This investigation was done by the Koninklijke Shell, Amsterdam. The concentrations were then compared with those obtained by conventional chemical balances.

Differences in Temperature Between Gases and Particles. It was considered possible that there might be differences in temperature between the flame gases and the particles associated with them. These differences might well be greater if the gases and particles had not followed the same path.

A comparison was made by the staff of the British Coal Utilisation Research Association, Leatherhead, between a suction pyrometer and a venturi pneumatic pyrometer in order to see if any differences in temperature between the particles and the gases could be determined.

Input Variables

Coal: Faulquemont Lorraine 8 per cent ash 42 per cent volatile matter (D.A.F.)
Fineness: 88 per cent below 74μ (200 mesh Tyler)
Moisture: About 1.5 per cent
Coal rate: 120 kg h^{-1} (0.81 × 10^6 kcal/h)
Primary air: quantity 108 Nm^3 h^{-1} (12 per cent stoichiometric)
Temperature 98 C
velocity 34 m sec^{-1} (at 98 C)
Secondary air: quantity 860 Nm^3 h^{-1} (98.5 per cent stoichiometric)
Temperature 400 C
velocity 0.8 m sec^{-1} (at 400 C)

The primary air and coal were injected into the furnace through a central tube of 39 mm diam and the secondary air entered as a stream concentric with the primary via an annulus, of 760 mm O.D. and 176 mm I.D.

Experimental Results

AERODYNAMIC PROCESSES

The concentration and velocity profiles for free turbulent jets where the mixing is a function of primary fluid momentum have been studied by various workers, cf. Hinze (11). It has been shown (12) that an enclosed jet of the same type can be considered, as far as mass entrainment into the jet is concerned, as behaving similarly until it is affected by the walls of the enclosure. The system studied here, with a surrounding annulus of slowly moving secondary air, is similar though not identical with the situation in a cement kiln, and is the first step away from the turbulent diffusion jet towards the case of concentric jets where the fluid in the surrounding annulus also contributes energy to the mixing processes. A first approach to the study of this problem is given by Tissandier, (8) but it is useful to see how the condition studied here compares with the simple single jet.

Velocity Distributions. The flame was projected centrally along the axis of the furnace and had a shape similar to a turbulent diffusion flame. The primary burner was inclined downward slightly (about $2^1/_2°$) so that the effect of buoyancy on this slow moving flame would not lift it too near to the roof and out of the region where measurements could be made. When the axial velocity falls to less than about 10 m s^{-1}, however, this effect is quite pronounced. Fig. 5 gives the velocity contours.

Recirculation, due to the static pressure differential, occurs all round the main forward stream, but preferentially under the roof and in the two bottom corners of the furnace. The area of cross-section taken up by recirculating gases is large and hence the actual velocities are rather small and difficult to measure. Values of about 2.0 m s^{-1} were observed, but it was not possible from the velocity measurements taken to define the limits of the recirculation zones. (Subsequent development has enabled much lower velocities to be measured.)

The secondary air enters at a temperature of 400 C and a mean velocity of 0.8 m s^{-1}. Being colder than the furnace atmosphere, it tends to fall as well as being entrained by turbulence into the primary stream. This falling stream of secondary air can be seen in the vertical section of velocities (see Fig. 5) and in the temperature (see Fig. 16). At a distance equal to about 1.5 furnace widths (2.4 meters) it meets the reverse flow of recirculating gases and this produces a region of instability, the general result of which is that the mixture of secondary air and recirculated products rises around the outside of the main jet. This can be seen in both the velocity pictures.

The recirculating gases above the jet do not meet such a strong forward current of air, and therefore continue until much nearer the burner where they are then mixed with the secondary air. All the above phenomena are similar to common experience with gas and oil flames studied previously.

The reciprocal of the axial velocity for a free jet is a straight line of which the slope is a function of the "equivalent nozzle diameter." This is a property of the free jet and is associated with a constant angle of spread, the mass of material entrained being proportional to distance from the burner. The same property applies to an enclosed jet so long as it is not affected by the walls of the enclosure. When this occurs the decay in axial velocity is more rapid and the reciprocal axial velocity curve is no longer linear. The "equivalent nozzle diameter" for a single jet as defined by Newby and Thring (12) is that nozzle which passes the same mass flow, at the same momentum as the actual nozzle, but with the density of the final mixture.

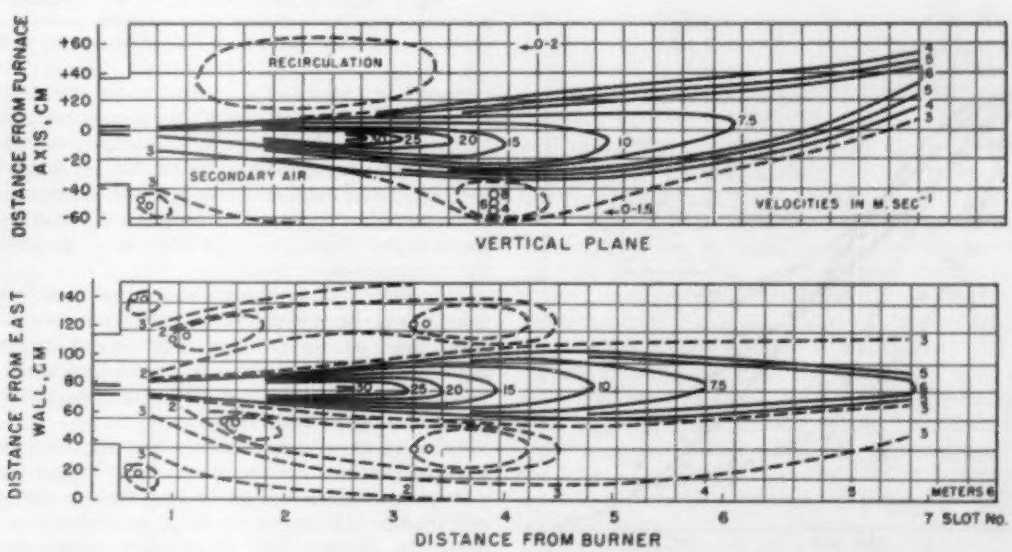


Fig. 5—Velocity contours in vertical and horizontal planes parallel to furnace axis

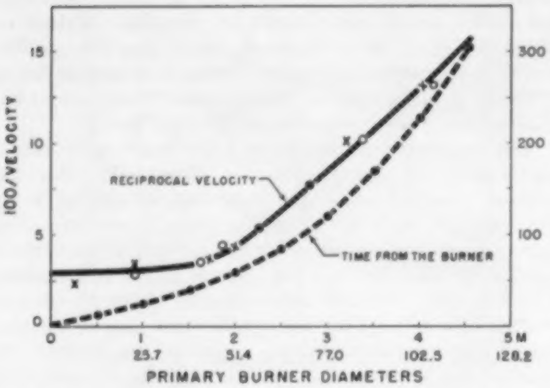


Fig. 6—Reciprocal of axial velocity and time from the burner

In this case the reciprocal axial velocity (see Fig. 6) is a straight line after about 45 primary burner diameters. This means that after this distance, the combined stream behaves as a single jet. This can also be verified from Fig. 7 where the radial distribution is shown to be constant between 1.6 and 4.1 meters from the burner. If it be assumed that the primary and secondary streams mix before this distance then an "equivalent nozzle" can be calculated which is based on the total mass flow and total momentum and the density of the final mixture. This gives an "equivalent nozzle" of 196 cm. From single jet theory it is also possible to calculate the equivalent nozzle (d') for the combined streams after complete mixing, from a knowledge of the slope of the full line in Fig. 6 as:

$$d' = \frac{x}{6.5} \times \frac{V_{xo}}{V_{oo}} \text{ cm}$$

substituting in this case:

$$d' = \frac{143 \times 10^4}{V_{oo}} \text{ cm}$$

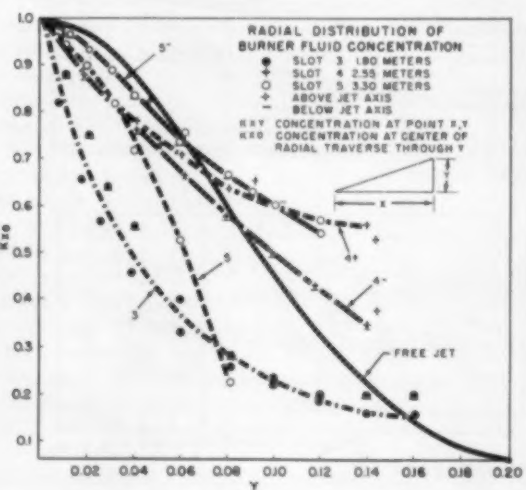


Fig. 7—Radial distributions of velocity

where V_{xo} is the axial velocity at a distance x from the origin and V_{oo} is the velocity at the origin. For single jets V_{oo} is taken as the velocity in the nozzle (here = 34.2 m s^{-1}) and this would give an equivalent diameter of 418 cm. It has been shown however (8) in certain concentric jet systems that the axial velocity rises on leaving the nozzle (cf. the point near the burner in Fig. 6), and it is suggested that the position at which this maximum velocity occurs be considered as the "origin" of the combined jet system. In this case it would require a maximum velocity of 67 m s^{-1} to give an equivalent diameter of 196 cm as calculated from considerations of total mass flow and momenta. This is not unreasonable.

Concentration Distributions. In a free jet the distribution of burner fluid concentration is almost the same as the distribution of velocity. In an enclosed jet however where there is recirculation within the enclosure, the

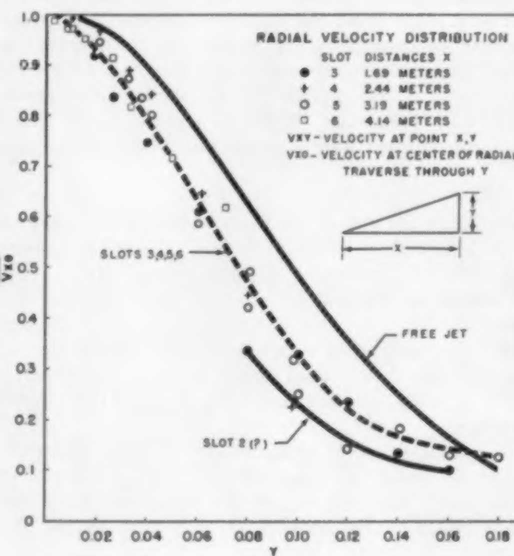


Fig. 8—Radial distributions of burner fluid concentration
+ following arabic numerals refers to measurements above the flame axis
— after the arabic numerals refers to measurements below the flame axis

surroundings consist of a mixture of air and recirculated products and these recirculated products are themselves a mixture of air plus burner fluid. As long as momentum and pressure are conserved within the jet it will entrain the same total mass as a free jet, but the concentration of fluid originating from the burner will become progressively higher than a free jet because of the presence of the recirculation.

This means that whereas the radial distributions of velocity expressed non-dimensionally may be constant in an enclosed jet, the radial distributions of concentration of material which has originated from the burner cannot be constant in an enclosed jet. A comparison between Fig. 7 and Fig. 8 illustrates this.

From an aerodynamic aspect it is important to know how the particles behave in relation to the gases. Ultimately of course if the jet be long enough, the particles will tend to fall out of the gas stream, but calculations based on Stoke's Law show that within the flame studied there would only be a fall of the order of 0.5 cm after 5 meters for particles of diameter 10 at the edge of

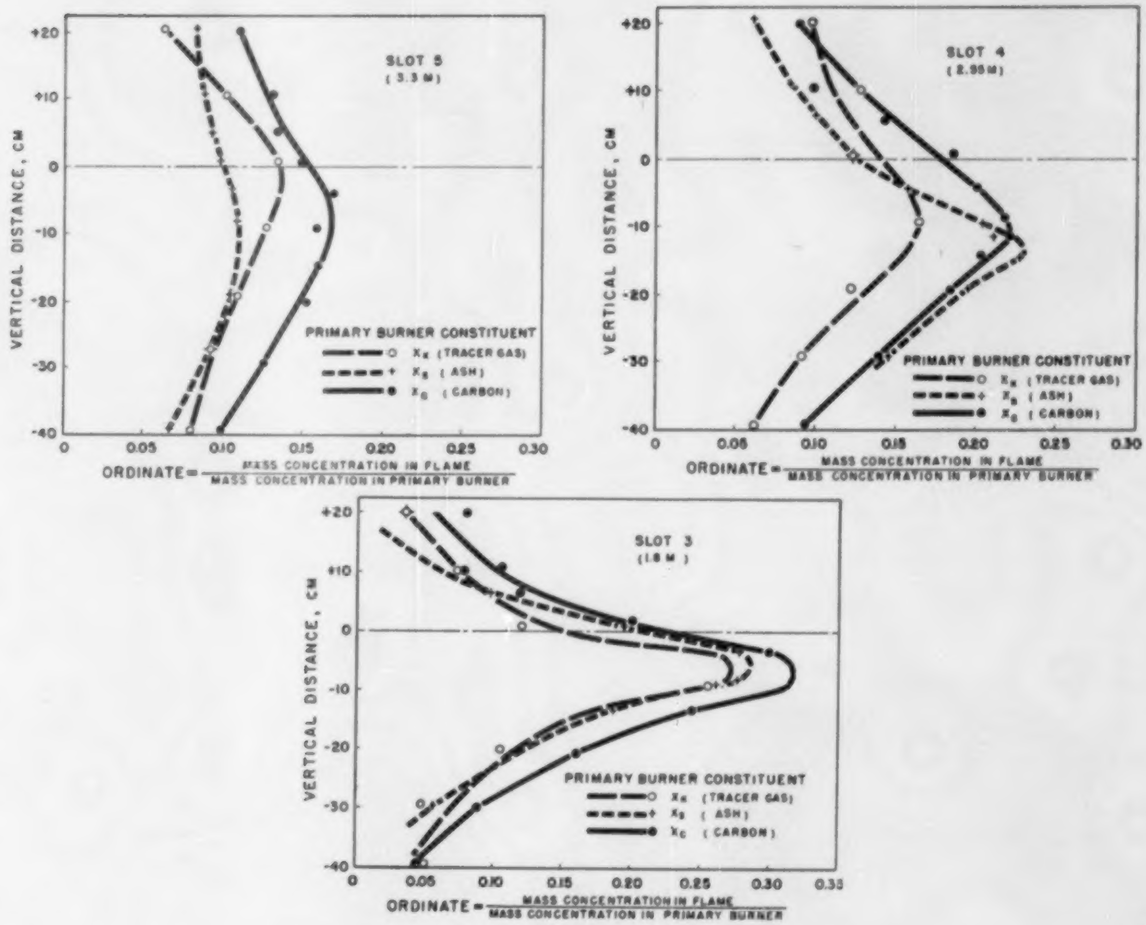


Fig. 9—Comparison of distributions within the flame of constituents present in the primary burner fluid

the jet. This is from considerations of terminal velocity only. Fig. 9 shows the distribution of constituents present in the primary burner fluid (coal plus primary air) for vertical traverses at three distances from the burner. The ordinate is non-dimensional and represents the concentration of each constituent at the point concerned divided by its concentration in the primary burner.

Concentration of constituents: (*a*) x_k—Calculated from a krypton balance based only on pure gases which were presented in the primary burner. This is independent of the particles and of any combustion phenomena.

(*b*) x_s—Calculated from an ash balance, based on solid particles which have come from the burner to the point under consideration. This is independent of any combustion phenomena.

(*c*) x_c—Calculated from a carbon balance; refers to all the carbon including that which remains as solid residue with the particles, that which is evolved with the volatile matter and that which has burnt to form CO or CO_2. It is thus concerned both with the particles and with the gases that have originated from them and which may be in various stages of combustion.

These calculations do not differentiate between burner fluid which has traveled directly to the point under consideration and that which has recirculated in the furnace. In this particular flame it was visibly evident that the amount of ash recirculating was small and this will introduce a difference between x_s and the other two factors, which is relatively unimportant in the center of the jet near to the burner, but which tends to give lower values than for the gaseous tracers further away from the burner, and also above the jet axis.

For the first part of the furnace most of the recirculation occurs above the flame and hence there will be more "gaseous carbon" and krypton above the jet axis than below. It would be expected that the ash and the carbon would agree in the center and below and the carbon and krypton would tend to agree above the jet.

Unfortunately the data are insufficient to draw any quantitative conclusions. It can be said, however, that up to 1.6 meters from the burner, time mean samples show little difference between the aerodynamic behavior of the particles and gases. Beyond this distance qualitative agruments may be advanced to explain the differences, but more experimental confirmation is needed.

Fig. 10 shows the shape of the flame as determined by the total concentration of solid particles. The value of 10 mg l^{-1} is about the concentration of ash only after

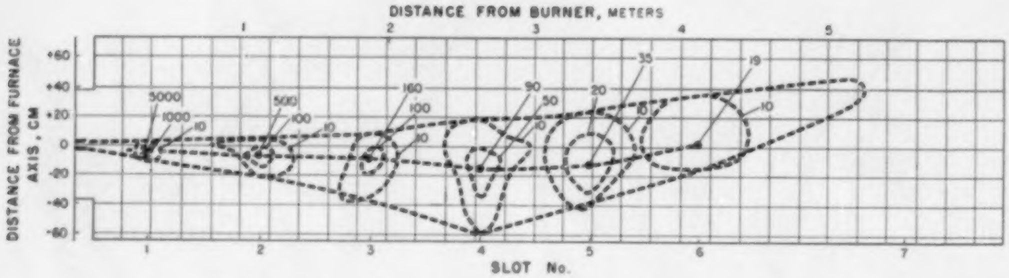


Fig. 10—Shape of flame from concentrations of solid particles (mg l^{-1})

complete combustion. The outlines shown at each measuring slot are the cross-sectional pictures drawn to the same scale. Two things are evident from this figure. The first is that the position of the maximum concentration closely follows that for the maximum velocity (see Fig. 5), and the second is that it seems as if the flame is rotating about 45° between each measuring point. This is about 3 revolutions per second. The radial distribution of the particles using ash as a tracer element is given in Fig. 11. It is difficult to conclude what shape the distribution has from this figure and the best straight line through each set of points has been given solely for clarity. The important point is that the distribution of the solids shows an angle of spread which increases at increasing distances from the burner. This should be compared with that of the velocity (see Fig. 7), which has a constant angle, slightly narrower than that of a free jet, and the gas concentration (see Fig. 8) which exhibits the effect of recirculation, as has been found in previous trials (13).

Fig. 12 shows a diagrammatic representation of the spread of the gases and particles. This is based on the half-peak velocity for the gases and the half-peak concentration for the particles.

In view of the other evidence that the whole jet is revolving slowly, the spread of the particles until they are affected by the furnace walls might be accounted for by centrifugal force. The above discussion emphasizes

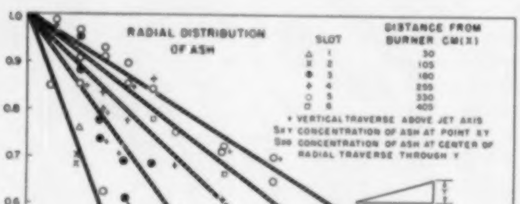


Fig. 11—Radial distribution of ash

that in this type of slow-moving flame the aerodynamic mixing between the two gaseous streams may not be completely followed by the particles, and this may make it difficult to correlate aerodynamic with combustion phenomena except in a qualitative manner.

Combustion Processes

Behavior of Particles. On entering the furnace the raw

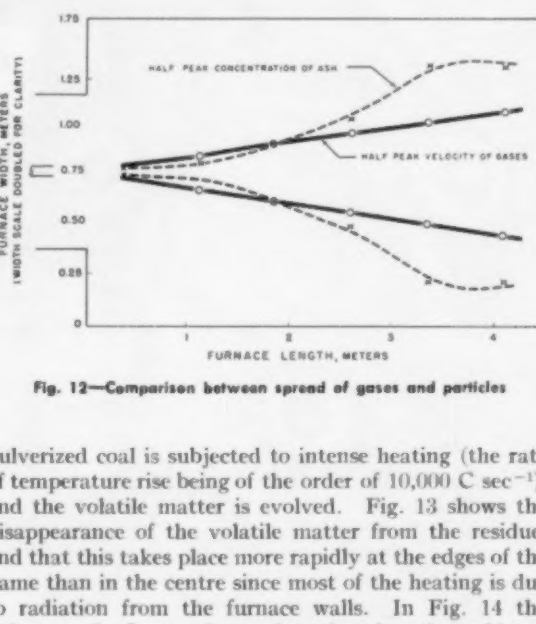


Fig. 12—Comparison between spread of gases and particles

pulverized coal is subjected to intense heating (the rate of temperature rise being of the order of 10,000 C sec^{-1}), and the volatile matter is evolved. Fig. 13 shows the disappearance of the volatile matter from the residue, and that this takes place more rapidly at the edges of the flame than in the centre since most of the heating is due to radiation from the furnace walls. In Fig. 14 the values on the flame axis are plotted against the residence time and it can be seen that 50 per cent of the volatile matter is evolved in 20 millisec, and 95 per cent in 50 millisec. These curves are based on analyses of the solid material from within the flame and hence do not show the rate of combustion of the volatiles, but only their rate of evolution. The other curve shows the burning away of the carbon residue. 50 per cent of this requires 100 millisec and after 350 millisec more than 10 per cent remains.

The processes of coal swelling and the formation of semicoke and cenospheres, of volatile evolution and thermal cracking to produce carbon black are described by Alpern *et al.* (14) after a microscopic study of particles collected from various points within the flame.

Combustion. The first part of this flame has the general form of a cool central core of partially burnt fuel

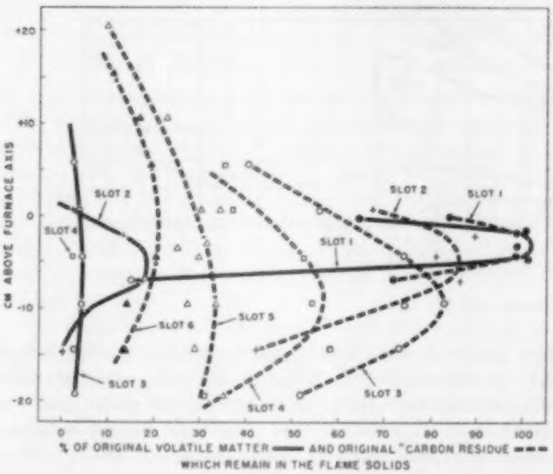


Fig. 13—Evolution of volatile matter and combustion of the carbon residue

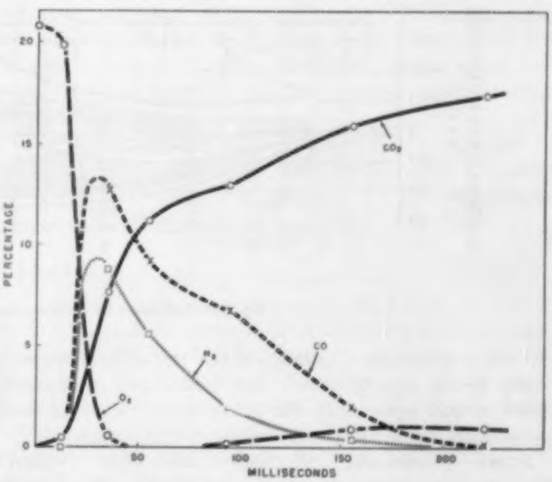


Fig. 15—Gas analyses on flame axis

surrounded by a hot sheath of intense combustion. In this region one is concerned almost entirely with combustion of the volatiles. Fig. 15 shows the rapid appearance of unburnt gases which corresponds to the sudden change in the character of the coal (see ref. 14, Fig. 3).

Fig. 15 concerns the axis of the flame where the temperature is lower and where for the first part of the flame only the primary air is available for combustion. The sharp disappearance of oxygen and rise of CO_2 implies that even here combustion follows immediately after evolution for some of the volatile matter. The above phenomena take place within the first 45 millisec on the flame axis and in the hot outer sheath they will of course occur even more quickly.

Between 45 and 75 millisec there is no oxygen on the flame axis and the rate of rise of the CO_2 curve is much less. This implies that combustion is here governed by the rate of arrival of the secondary air by a process of turbulent diffusion through the other sheath.

After about 80 millisec the rate of production of CO_2 increases again. The important phenomenon here is that the oxygen also increases. This suggests that there is now sufficient air available for combustion but that some other factor is limiting the rate at which the oxygen is being used. In the case of the unburnt gases this is due to the macro turbulence—the "unmixedness" of Hawthorne, Weddel and Hottel (15). In the case of the solid residue it is probably due to molecular diffusion of oxygen towards and products away from the surface of the particles. After 160 millisec there is more oxygen than is required to combine with the unburnt gases and hence molecular diffusion mentioned above then becomes of increasing importance.

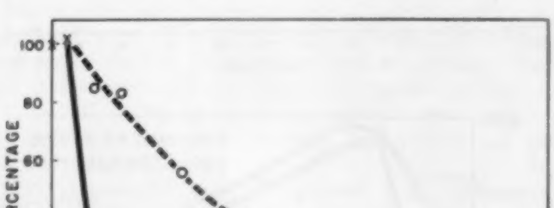


Fig. 14—Evolution of volatile matter and combustion of carbon residue on flame axis (solid line represents volatile matter, dashed line shows carbon residue)

Temperature Differences between Particles and Gases. Because of the nature of the disintegration and burning of coal particles and also because of the possibility of different paths followed by the particles and gases, there is a possibility that the two constituents do not have the same temperature. A comparison was made during these trials between the temperatures as measured by a suction pyrometer and a venturi pneumatic pyrometer. This comparison was made by the staff of the British Coal Utilization Research Association and has been mentioned by them in a recent publication (16).

The suction pyrometer records a temperature which is chiefly due to heat received at its thermocouple junction by convection from the gas stream. To a smaller extent it is affected by radiation from the surrounding shields. The particles in the gas stream which are drawn into the shields will also give up heat both by impingement and by radiation. It is reasonable to conclude therefore that if the particles have a different temperature from the gases, then the temperature observed by a suction pyrometer will be somewhere between the two although it is not at the moment possible to say quantitatively what it will be.

The venturi pneumatic pyrometer on the other hand records the change in density of a constant mass of gas flowing through two venturis in series at different temperatures. The gas temperature so obtained is virtually independent of the presence of particles at a different temperature.

The response time of the suction pyrometer is about two minutes whereas that of the venturi pneumatic is almost instantaneous. This latter instrument therefore was able to show in almost all regions of the combustion zone that short-term variations (a few seconds) of ±50 C were present.

Differences of 100 C in the mean temperature between the two instruments were apparent particularly within

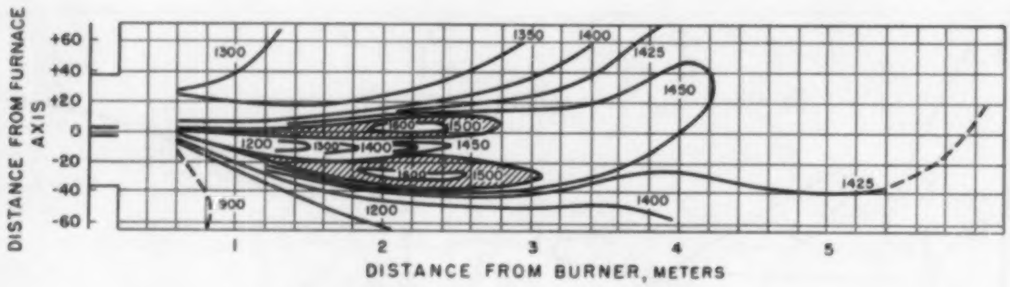


Fig. 16—Isotherms in vertical plane of furnace axis (C)

the zones of intense combustion but the differences were of the wrong sign to permit any qualitative explanation which would agree with the other data. Further work to compare these two instruments is being planned.

Flame Temperature, Radiation and Heat Transfer. Fig. 16 shows isotherms in a vertical plane through the furnace axis. The cool flame centre and hot outer sheath are clearly seen as also is the flame lift after 3 meters. The temperatures outside the main jet are higher above the flame than below because there is more recirculation above than below. These isotherms are based on many observations made with a suction pyrometer.

Measurements of flame temperature were also made by optical pyrometer viewing through the furnace doors. These temperatures agree very closely with the maxima obtained in the nearside hot sheath with a suction pyrometer.

A grooved water-cooled target was slowly moved across the flame and the flame radiation between this and one wall was measured with a radiation pyrometer. The results of this show that until 3 meters from the burner the radiation originating from the nearside of the flame is as high as that due to the whole cross-section. This means that the local flame emissivity is so high that only the nearside of the flame makes any contribution to radiant heat transfer to the walls of the enclosures. It also means that within this zone any change in flame radiation properties must come as a result of changes in the temperature of the outer burning sheath.

Fig. 17 (*a*) shows the maximum narrow angle flame radiation to have its peak corresponding to the region of highest temperature in the hot sheath shown in Fig. 16. The "Schmidt temperature," or equivalent black body temperature T (max) shown in Fig. 17 (*c*) is that temperature at which a black body would radiate at the same rate at which the flame is radiating. It is obtained from measurements of radiation made by a radiation pyrometer as:

$$T = \sqrt[4]{\left(\frac{R_1 \times R_3}{R_3 - R_2 + R_1}\right)\frac{1}{\sigma}}$$

where:

R_1 = flame radiation measured with cold background.
R_2 = flame radiation measured with a hot black-body background. In this case the furnace wall.

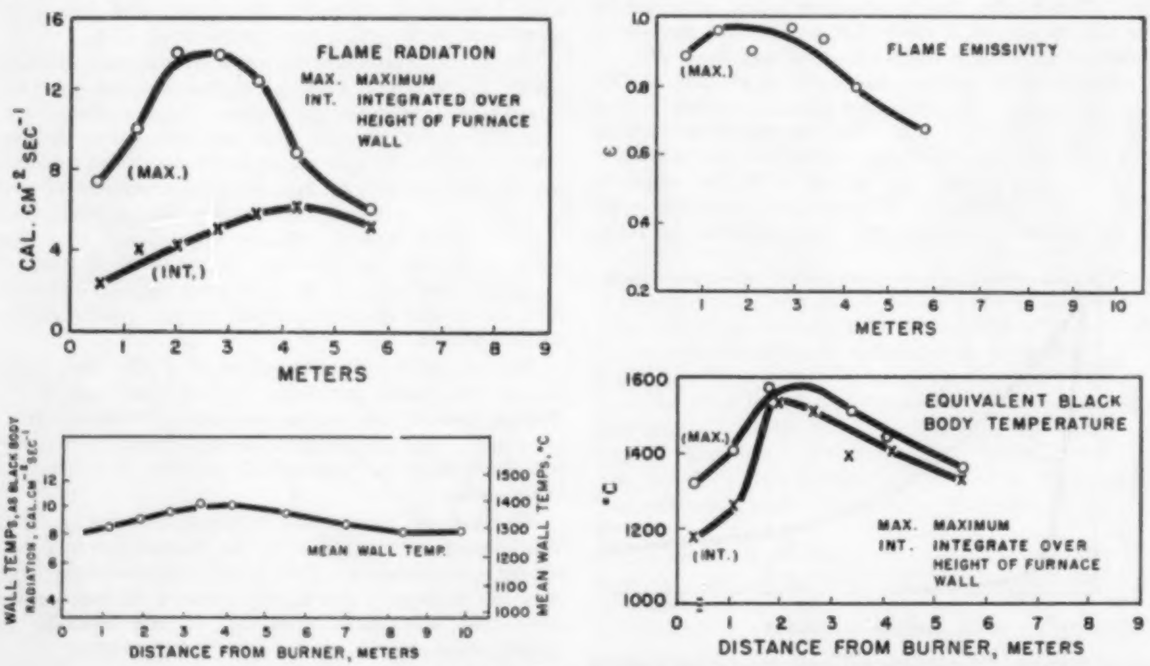


Fig. 17—Radiation, (a), emissivity, (b), equivalent black-body temperature, (c) and wall temperatures, (d), at given distances from the burner

R_2 = temperature of furnace wall expressed as black-body radiation.
σ = Stefan's constant.

It is in close agreement for the centre part of the flame with the independent measurements of temperature made with an external optical pyrometer, and suction pyrometer in the hot flame sheath. After the end of the burning flame the emissivity drops and the above agreements do not hold. The emissivity however remains much higher than that of gaseous and liquid-fuel flames after combustion has ceased, owing to the presence of the ash particles.

The flame radiation integrated over the whole height of the furnace wall rises until a distance of 4 meters from the burner as a result of the widening of the flame. It is the integrated radiation and the longitudinal radiation from sections of the flame to areas of wall not directly perpendicular to them which even out the wall temperatures.

This can be seen qualitatively in Fig. 17 (*d*) where the maximum wall temperature is at the same distance as the peak value of the height-integrated radiation of Fig. 17 (*a*).

Conclusions

This experiment provides a picture of a pulverized-fuel flame, similar to that used in a cement kiln.

Aerodynamics. (*a*) A concentric jet system with a slow moving secondary stream was used. The general flow patterns, concentration distributions and recirculation are of the same qualitative form as those obtained with a single enclosed jet in which the secondary stream fills the cross-section of the enclosure.

(*b*) The two streams join after about 45 primary burner diameters and, as far as velocity distributions are concerned, they behave as a single stream with an angle of spread similar to, but slightly narrower than, a free jet.

(*c*) After 45 diam the angle of spread of the solid particles increases linearly with distance until they are affected by the walls. This increase is possibly due to centrifugal force as in this case the whole jet was rotating.

(*d*) The use of radioactive krypton as a tracer gas for aerodynamic studies in burning flames is simple and effective. Insufficient data were collected in this particular case for quantitative conclusions to be drawn.

Combustion. (*a*) On entering the furnace (with walls at 1300 C) 95 per cent of the volatiles are evolved in 50 millisec. During evolution there is a possibility that the residue disintegrates to smaller sizes and that in a deficiency of air the volatiles will crack and produce soot.

(*b*) The combustion of the volatile matter can be considered as taking place very rapidly so that the rate controlling process is the physical mixing of air and fuel by turbulent diffusion.

(*c*) The combustion of the residue is a much slower process. After 350 millisec more than 10 per cent of the residue remains unburnt. Combustion here is probably governed by molecular diffusion of oxygen towards and products of combustion away from the particle surface.

Flame Temperature, Radiation and Heat Transfer. (*a*) A pulverized-fuel flame has an emissivity which approaches unity for over half its length. This means that the gas temperature in the hot flame sheath and the "Schmidt radiation temperature" are almost equal and are also almost equal to the temperature observed when using an optical pyrometer.

(*b*) As a consequence of the above, any changes in flame radiation properties must come as a result of changes in the temperature of the outer burning sheath.

Investigators

The visiting investigators who assisted during the Combustion Mechanism trial were: M. Denis, M. Girardot and M. Kissel, Institut de Recherches de Sidérurgie; M. Kilen and M. Maille, Stein et Roubaix; M. Ordener and M. Gailhbaud, Glaciéres de St. Gobain; M. Bouriot, Office Centrale de Chauffe Rationelle; Miss Baylis, Mr. Holland and Mr. Thurlow, British Coal Utilization Research Association; Mr. Mitchell, University of Leeds, Mr. Hislop, James Howden and Co., Ltd.; Mr. Peploe, Central Electricity Authority; Mr. Harmsworth, British Petroleum Co., Ltd.; Dr. Roxborough, Esso Petroleum Co., Ltd.; Mr. Hofstra, Mr. Kuyper and Mr. Stemerding, Kon./Shell Amsterdam; Mr. Ferrell and Mr. Stanfield, Massachusetts Institute of Technology.

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Kellogg's New Power Piping Plant

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With these new facilities, Kellogg is equipped to undertake any steam-electric or nuclear assignment with greater efficiency, economy, and speed than ever before in its 40-year history of power piping leadership.

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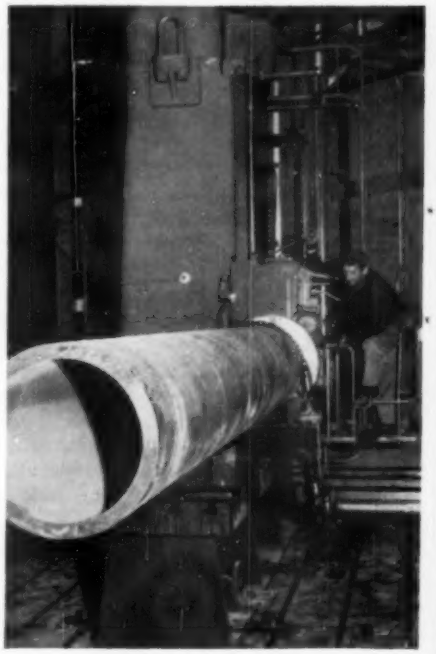

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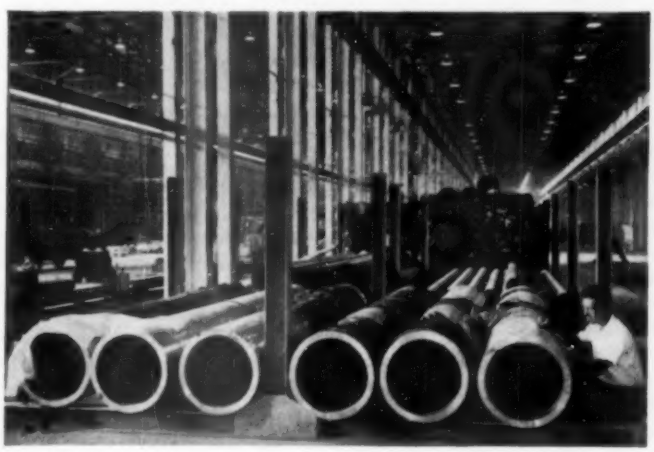


Above: Welding is a major phase of Kellogg's operations. Here, two thin-walled sections of stainless steel power piping are being joined by K-Weld—an inert gas-shielded technique of arc welding, patented by Kellogg, which assures long life.

Above: Raw materials bay, 40-ft. wide, extends the entire 900-ft. length of the plant. Piping and fittings are conveniently drawn from storage by overhead cranes and placed in the production line at any point in a planned manufacturing sequence.

Left: One of the new boring mills at Williamsport. Piping in machine is a stainless steel section—to be installed by Kellogg field erection specialists in the reactor sphere of a nuclear power station.

Left: Front entrance of Kellogg's new Headquarters Building. This ultramodern office building houses administrative, engineering, estimating, and accounting departments of the Power Piping Division. Sales offices remain at 711 Third Avenue, New York, N.Y.

Twenty First Annual Water Conference

THE Twenty First Annual Water Conference sponsored by the Engineers' Society of Western Pennsylvania scheduled for October 24–26, 1960, was held at its usual site, the Penn-Sheraton in Pittsburgh. Attendance was very close to 600, the highest in some years. A very enjoyable "get together" party was employed to salute this highly regarded annual affair. Below we present abstracts of the papers we hold to be of interest to the COMBUSTION reader.

Ion Exchange

"The Mechanical Development of Ion Exchange" was the opening paper by **Paul H. Caskey,** Illinois Water Treatment Co. The industry has made remarkable strides, said Mr. Caskey, in developing the resins. It has similarly been giving considerable attention to the new developments in components—tanks, linings, distribution, piping, valves, instruments and controls. It has been careful not to go overboard for something new just because it is new but it has been open-minded and not turned things down just because they were new.

The tanks, of course, are pretty well standardized. They are vertical, cylindrical vessels sized to handle the required volume of resin and permit the specified flow rate. Both resin volumes and flow rates have increased markedly. Resin beds of six feet depth are common with flow rates of eight to ten gpm and even higher. Ninety per cent of the tanks going into utilities meet code specifications.

Tank linings are mostly $^3/_{16}$-in. vulcanized sheet rubber and the author's company expresses a feeling that sheet PVC is at least as good, with the other plastics promising good results when their application is perfected. The nuclear units have been specifying stainless steel and because of cost and also the advantages of a correctly lined carbon steel their application to general ion exchange service does not seem warranted in the author's view.

The three commonly used distribution systems—header lateral, hub and radial lateral and full area screen—all have advantages and disadvantages. But with proper design all will work well.

The support bed, usually either quartz or anthracite, has been undergoing some investigation. The fear of silica pick-up from quartz brought about a heavy interest in anthracite. But anthracite, with a tendency to retain caustic regenerants and require a prolonged rinse record, is not overly satisfactory. The author's people have felt quartz gives no more silica than anthracite and tests have confirmed this feeling in large, full scale equipment. The Detroit Edison Co. and Dow Chemical Co. have both replaced anthracite with quartz in large anion exchangers—the latter in four 12 ft 6 in. columns—and both report improved rinse characteristics and no appreciable increase in silica.

Piping materials have evolved with plastics development. Rubber lined steel has been used for the start for larger sizes but for piping 2-in. I.D. and less the industry has used a succession of plastics as newer, better ones became available. The larger pipes have seen the introduction of Saran lined steel, Penton lined units for higher temperature, glass lined, solid PVC and a host of others.

Valves have similarly undergone some explorations. The long accepted Saunders valve is being challenged by pinch valves and ball valves with some limited use of stainless steel valves.

Resin removal and regeneration in external beds, first employed by Rohm & Haas in the early development of monobeds, is being revived. (*Editor's Note:* See the Calise, Spillane paper following the discussion on this paper.)

Automatic plants have increased considerably. Almost a third of those systems of 25 gpm or more and 90 per cent of those 100 gpm or larger are automatic. Yet the speaker felt that some operator attention is warranted. Instrumentation to a large measure goes hand in hand with automation. The more automatic the plant the more instrumentation and the instrumentation should include considerable recorder units.

M. M. Baker, Commonwealth Edison, shared his discussion with **A. B. Sisson** of the same company. They felt that items like sealed relays, solid state controls have added to greater reliability and reduced preventive maintenance.

Tanks are something of a problem in an erection job. The linings are often badly abused while installing internals. Their mechanical design, in these discussors' views, should be such that once installed they can be forgotten. Opening and loading an exchanger to effect repairs is too costly an operation.

The hydraulics of distribution is another area where much more thought should be given. High head losses with respect to increased power costs for pumping must be carefully evaluated.

As for piping material the authors are strong supporters of Saran lining. Valving, they believe, is a subject for a full session. The double diaphragm type valve they find has a very important advantage in a built-in leak detector that makes trouble shooting much easier. Saunders valve operators seem tempermental and with automation the valve operators must be designed to "fail safe."

H. A. Klein, Combustion Engineering, Inc., in his discussion pointed out that a deionizer is a unique piece of equipment in the power plant employing hazardous chemicals with which the average plant operator is not acquainted. Special efforts in the way of education must

be developed. For example, it should be axiomatic, Mr. Klein said, to assume the automatic controls will fail to function at 4 a.m. of a Sunday with the company's only qualified expert on vacation. The operator should be capable of safely regenerating the deionizer manually even when the normal regenerant feed system is down. Performance of a manual regeneration, Mr. Klein believes, is one of the best ways for an operator to educate himself on the numerous steps involved in the deionization process.

V. J. Calise and **D. M. Spillane,** Graver Water Conditioning Co., then collaborated on a paper "The Place of External Regeneration in the Design of High Rate Condensate Scavenging Systems." The authors expressed a conviction they had held that the central station engineer had focused so much attention on the extreme makeup purity that he had overlooked the much greater source of solids contamination from the condenser weepage or leakage and internal cycle corrosion which cannot be dealt with except by condensate or feedwater scavenging, filtration and demineralization.

A giant step of simplification in the authors' opinion is in the making. That step will involve (1) an economical high rate condensate scavenging plant working at the hotwell to remove all impurities from this cycle, (2) use of steel tubes in heat exchangers in place of copper alloy, (3) a simplified variation of "zero solids treatment" using ammonia and/or hydrazine for protection of steel surfaces against corrosion.

To the authors' way of thinking the extraordinary makeup purity at considerable cost with demineralizers or evaporators cannot be justified when condenser leakage or internal corrosion truly control boiler plant operation and on-time availability. The European power industry has accepted this situation more generally and employed condensate scavenging of a sort in effecting control but no serious attempt to design cycles with internal condensate purification equipment was made until nuclear power plants and supercritical, once-through boilers were developed in the U. S. The stations now employing condensate scavenging are the American Electric Power Philo Station, Unit 6, the Philadelphia Electric Co. Eddystone Station, Units 1 and 2, and Cleveland Electric Illuminating Co. Avon Lake Station, Unit 8.

In the above three examples design and operating results have been remarkably consistent. The condensate purification systems were designed for between 20 per cent and 50 per cent of the total condensate flow. In all cases the demineralizers were in-place regenerated, preceded by cellulose pre-coat filters designed for 2 to 4 gpm per cu ft flow rates. The demineralizers, in turn, were designed for flow rates of 15 to 25 gpm per sq ft. The authors' estimate of equipment costs for these installations was put at $2.00 per kw.

To make the advantages that these stations experienced generally available to the utility industry it was necessary to make a design competitive and economic for subcritical conventional steam plants and hence at a cost figure well below the $2 per kw cited above. In 1958 Baltimore Gas and Electric Co. contracted for a 100 per cent condensate purification installation in connection with a subcritical once through boiler using sea water for condenser cooling. Its equipment costs ran $2.25 per kw. The one promising approach to lowering these costs seemed to the authors' minds to be the use of external regeneration of the ion exchange mixed bed resins by withdrawal of exhausted resin beds from the units to a separate outside regenerating facility.

When the Little Gypsy Station of the Louisiana Power & Light Co. came along they called for a makeup water from the Mississippi River, clarified and filtered prior to demineralization in a dual train cation-anion unit with mixed bed polishers. The cost of this equipment was about 60 cents per kw.

This unit was looked at for condensate scavenging. The cost for filtration and demineralization equipment sized for 100 per cent condensate treatment (while all units are in service) meant an expenditure of about 50 cents per kw. Because of the internal purification the polishing mixed bed demineralizers on the original makeup demineralizer could be eliminated. Further, when the decision was made to go to condensate scavenging the original makeup demineralizer was revised from a dual train to a packaged; pre-built, simple, single-train two bed demineralizer. This reduced the cost of the makeup equipment from its original estimated 60 cents per kw down to 40 cents per kw giving a differential between the original choice and the 100 per cent condensate scavenging arrangement (50 cents plus 40 cents) of 30 cents a kw.

The authors pointed out that Little Gypsy is using a low dissolved solids cooling water as against the Baltimore Gas and Electric Co.'s seawater. Further Little Gypsy is a drum-type boiler installation which can be blown down in an emergency so that complete dependence on the demineralization system such as Baltimore needs does not hold for Little Gypsy. This was considered in the design.

Southern California Edison Co. has purchased for its two subcritical, once-through boiler systems using sea water for condenser cooling at Huntington Beach a single, condensate scavenging plant which can handle 100 per cent of the condensate from either Unit 3 or 4 or 50 per cent of both units at the same time. The equipment cost including automatic controls is about 75 cents per kw.

TVA for its Paradise 1 and 2 installations have gone to 100 per cent condensate purification systems including filtration equipment and externally regenerated demineralizers. The flow from the condenser for each of the 600 Mw units is 6900 gpm. The cost for the condensate scavenging equipment is 50 cents per kw.

Mr. Calise and Mr. Spillane then discussed the operating advantages of this system.

Donald G. Downing and **Robert Kunin,** Rohm & Haas Co., took up the subject "The Performance of a New Highly Stable Sulfonic Acid Cation Exchange Resin." This paper described the stability and operating characteristics of a new resin (Amberlite 200) which is said to be highly stable, of the sulfonic cation exchange type. Data were presented demonstrating that this resin is more resistant to oxidative attack, osmotic shock, and physical attrition than any of the standard cation exchange resins currently available. There were findings advanced on the difference in degradation rates between the new resin and the stand-

ard resins in treating iron bearing waters. Operating results from large size commercial installations have confirmed the resin's stability and normal capacities that the laboratory tests had indicated.

L. F. Wirth, Jr., Nalco Chemical Co., in discussing the application of resins and the field checks on their operating characteristics remarked that (1) moisture content cannot be reliably used for comparison of degradation with this new product, (2) all styrene divinyl benzene cation resins tested by Mr. Wirth's group were affected similarly by oxidizing agents, (3) chlorine present in any significant amount must be removed with sulfur dioxide or sodium sulfite to obtain optimum demineralizer performance and resin life.

Donald E. Voyes, Duke Power Co., also submitted a discussion on this paper by reciting some of his company's experiences with the new resin. Prior to installing the new resin a 40 gpm mixed bed unit carrying another resin and operating on a filtered river water free of any significant organic content or industrial waste operated very poorly with a history of short resin life. This pattern was typical of the company's entire 5-year experience with demineralizers at three different installations involving two separate rivers.

By physically breaking the resin particles the company could restore capacity to the anion resin. Further it was clear that the cation was involved in the fouling because new or "restored" anion resins fouled in about 10 operating cycles when put in a mixed bed unit with a used cation but would demonstrate a "normal life" of 75 cycles when used with a new cation. The new resin overcame this completely and up to now (it is still going strong) has gone through 125 cycles.

Warm River Waters

In a session devoted to waste waters **H. F. Hatfield,** Pennsylvania Power & Light Co., discussed the recently charged offender, thermal waste. His paper "The Effects of the Discharge of Warm Water to Rivers" is the second paper commenting on this problem which we have heard within a week's period. The earlier one was presented by **L. W. Cadwallader,** Potomac Electric Power Co., before the Southeastern Electric Exchange in Washington, D. C., October 20, 1960.

Since 1956, Mr. Hatfield stated, Lehigh University Institute of Research has been conducting research on the Delaware River near Martins Creek, Pa., on the effects on aquatic life resulting from water discharged from the Martins Creek Plant of the Pennsylvania Power & Light Co. The Delaware is a remarkably clean stream so that the results of temperature could be clearly distinguished from those of organic or chemical pollution. Changes in geography, proportion of stream flow used, temperature conditions could affect the results and more data must be collected before definite decisions can be made on rivers in general.

Corrosion

M. C. Bloom, consultant with the U. S. Navy Research Laboratory, opened the program with his paper "A Survey of Steel Corrosion Mechanisms Pertinent to Steam Power Generation." The fundamental fact basic to the subject, Bloom pointed out, is that ferrous metals are thermodynamically unstable in contact with water or air and their usefulness in steam generating systems depends upon their capacity to form protective films. With this as a starter the author listed in tabular form the corrosion products of iron. These were then discussed one by one in terms of their appearance as a problem (that is, at room temperature, at boiler temperatures), their decomposition and any attendant problems and to some measure their control.

The author's investigation of corrosion revealed a number of interesting conclusions. Considerable work was carried out, for example, on the influence of pH on corrosion and the basic Berl and van Taack data was checked against the hydrogen effusion technique. With static systems the rise in pH brought about a rise in corrosion rate. From a Westinghouse report of experiments the author drew the conclusion that in high velocity systems, on the other hand, alkalization to pH of 10 to 12 is beneficial and, further, that the protection of the film increased with time at high pH. This last finding is not true with a low pH. The inhibition of concentrated caustic attack from sodium hydroxide by additions of phosphates or nitrates was mentioned as well as that of using a volatile alkali, ammonia or amines, instead.

In very much the same way the author discussed the laboratory surveys on the roles of the hydroxides, the chlorides, the phosphates, the addition of hydrogen and oxygen, and the formation of the magnetite films. Of the eight corrosion products known to form during the corrosion of steel in aqueous systems only those having the spinel structure (such as Fe_3O_4) are capable of forming adherent protective films. Their development and maintenance is the major problem in use of steel for steam generating systems.

P. D. Miller, Battelle Memorial Institute, commented on Dr. Bloom's statement that carbon steel corrosion increases in the pH range of 7 to 11.5 would be of interest to both research men and station operators. He did mention some slight differences in acceptable values for solubility products and pH.

D. L. Douglas, General Electric Co., cited earlier work he and Zyzes had been involved in which led to the conclusions that additions of sodium hydroxide to a pH of 11 did not reduce the corrosion rate of iron below that observed in deionized oxygen-free water at 600 F. These findings do not, in Mr. Douglas' opinion, mean that all treatment of boiler water with additives to raise the pH should cease. All it means is that we have a better understanding of the real function of such treatment. Increasing the pH is probably effective in preventing the breakdown of already formed protective films during exposure to air during periods of boiler shutdown.

Paul Cohen, Westinghouse Electric Corp., felt Dr. Bloom's paper was one of the best reviews of this subject. He limited his comments to the release of corrosion products from the corrosion film to the water and

the incorporation of water-borne corrosion products in the growing corrosion films. It is the combination of these two processes which is responsible for the fact that all surfaces in closed cycle water-cooled nuclear power plants outside of the reactor core become radioactive.

H. A. Cataldi, General Electric Co., raised the question can the measurements revealed by Dr. Bloom be extended to steam and to temperatures approaching 1000 F. Further, he hoped that Dr. Bloom and others like him would continue their basic studies and perhaps uncover a treatment that will protect turbines, boilers and assorted plumbing from standby corrosion.

The subject "Pretreatment—The Key to Effective Protection of Cooling Water Systems" was presented by **P. R. Puckorius,** Nalco Chemical Co. He reasoned that since the protective film or barrier, as he called it, is only as good as its bond to the metal it protects, the preparation step is of major importance. The simplest example is that paint should never be applied over a rusted surface.

In recirculating cooling water systems the usual procedure is to flush the system out with water and sometimes employ acid cleaning to remove mill scale and rust. But then very little is done until the entire system goes into operation. This wait may be some little time and corrosion products begin forming. During startup, to be sure, corrosion inhibitors are added at the maintenance or even high level dosages. But this may come too late.

The author's company set up a laboratory project to determine whether a single treatment could be developed to handle the new system's pre-operating corrosion problems. Solvent washing of new equipment reduced corrosion and fouling slightly, but did not prepare the metal for establishment of a protective film. Further, existing corrosion inhibitors that would satisfactorily meet the pre-operating conditions left behind an atmosphere that created troubles with the traditional operating cycle corrosion inhibitors. Eventually the laboratory project led to a completely new product—"Pretreatment." A number of field evaluations was run to determine the product's effectiveness.

W. A. Hess, Standard Oil Co., repeated the statements of Mr. Puckorius that there was a definite need for a "one-shot" pretreatment for metal surfaces. Finally when the new product of the author's was made available, Mr. Hess put it to the test on nine bundles of steel tubes used in fourteen coolers and condensers that use recirculated cooling water. Two of the bundles were opened for inspection after pretreatment. They were found to be colored a deep blue which Mr. Hess was told was typical for this type pretreatment. The units were then reassembled and put on the line.

The system experienced power failures, balky acid pumps, the pH of the circulating water went from 3.9 to 9.0 during the first year of operation. During the high pH the refinery operators expected phosphate precipitation, and during the low pH they anticipated pitting and corrosion. In fact, the water at the low pH turned a decided blue evidencing that at least some of the prefilm was being removed. Upon inspection there was very little evidence of a pitting type corrosion.

L. F. Probst, Betz Laboratories, Inc., introduced the information that pretreatment can be applied to corroded areas as well as clean surfaces and that the most effective results are obtained when the pretreatment chemicals are made of the same chemicals that are used from day to day in the normal corrosion control program.

Chemical Cleaning

The highlight of the first afternoon was a five-man panel on chemical cleaning with each man assigned twenty minutes to present his phase.

The lead-off man of the session, **S. F. Whirl,** Duquesne Light Co., acting as the chairman, defined the problem. As he pointed out, the problem of chemical cleaning is not whether to, but how to. Failure to clean the entire boiler system allows contaminants to collect and form deposits which could result in tube burnouts and costly maintenance. Outage costs for a highly efficient boiler unit today can run as high as $30,000 a day.

A. A. Pace, Duquesne Light Co., listed the common practices of the public utility industry today—namely, (1) manual and chemical cleaning of the condensate cycle; (2) a strong alkaline boilout of the boiler; (3) acid boilout; (4) alkaline conditioning of the boiler; (5) high pressure steam blowout of the main steam leads; as the methods employed for chemical cleaning. He then confined his remarks to steps 1 and 2.

The primary objectives, as Mr. Pace saw them, for manual and alkaline cleaning of the new boiler and condensate cycles are to remove construction debris, temporary protective coatings against atmospheric rust, loose mill scale, and water soluble and saponifiable lubricants used during construction. To accomplish these ends manual wiping and brushing are used to remove accessible grease and debris; the system is treated with a selected alkaline solvent, temperature controlled to remove oil, grease and protective coatings; and then a high pressure flushing is applied to carry loose solids to waste. Trisodium phosphate has been used by the speaker's company for years with good results.

Of equal importance, in Mr. Pace's opinion, to the proper alkaline solvent is to have sufficient pump capacity to move loose particular matter to waste.

A typical procedure was then described for the Company's Phillips Station, No. 4 unit.

R. L. Garner, Arizona Public Service Co., followed with his talk "An Experience in the Use of Filming Amines for Feedwater System Cleaning." The Saguaro Station, essentially a base loaded plant, was selected for the experimental work with filming amines because it was anticipated that soon considerable standby operation would be necessary.

Piping of 8 in. was installed from the boiler drum to the condenser hotwell to permit complete recirculation of the filming amine through the heater system, the economizers and the hotwell. It was decided to use the relatively high concentration of 100 ppm of the amine at 180 F for the cleaning solution and recirculate for a four-day period. The pH of the circulating solution varied from 5.5 to 6.0.

After the four-day period the systems were drained and considerable material removed from the hotwell. Filming seemed complete. Dismantling the 8-in. recirculation line disclosed a deposit of oxide and filming amine that had built up to $^1/_{16}$ in. The same buildup was observed on the inside structural parts of the hotwell. This, along with two wheelbarrows of sludge, was removed from each hotwell.

As. Mr. Garner reported, the results of the Arizona Public Service experiment indicated that a four-day recirculation period using octadecylamine was not suitable for a system that already has the normal amount of metallic oxides from several years' operation. Reduction in heat transfer was noticeable on all parts of the system but continued a problem on the lower pressure heaters. Apparently some schedule for periodic cleaning of the low pressure heaters will be necessary. It will be interesting to see if filming of a system before initial operation would result in the same condition.

L. E. Astrand, Borg Service International, Zurich, Switzerland, presented a paper on "European Experience on Complete Power Station Pre-Service Cleaning." In his paper the author stated acid cleaning of new boilers is now standard practice in Europe. New inhibitors have permitted higher temperatures. The application of neutralizing and passivation processes after acid cleaning gives a boiler surface free of mill scale and silica but possessed of a thin protective magnetite film. The pressure for cleaning of the complete feed cycle as well as the entire steam generating areas is a growing one.

The most common cleaning agent is inhibited hydrochloric acid, but for those units operating above 1000 F with austenitic steels sulfuric or citric acids have been preferred. A special circulating scheme is needed for some boilers and extra pumps for reheater sections. H. G. Heitmann will give a detailed paper at the ASME Annual Meeting in New York this November on a once-through boiler unit that makes use of its feedwater pumps for the acid cleaning.

Supercritical Plant

H. J. Vyhnalek and **C. D. Banks,** Cleveland Electric Illuminating Co., pooled their energies in presenting the paper "Water Treatment Experience During the Startup and Initial Operation of the Avon Supercritical Unit." Experience indicated these major sources of water contamination: (1) condenser leakage or "weepage," (2) miscellaneous auxiliary drains, (3) makeup water, (4) corrosion of materials within the cycle. To eliminate them a condensate bypass purification system was devised. This system employs no traditional storage reservoirs but rather has the bypass liberally designed to give in effect "dynamic storage."

The following functions are served by the system (1) protection of the cycle from contamination due to condenser tube weepage or tube rupture, (2) a means of polishing makeup water and miscellaneous drains, (3) removal of corrosion products from the cycle, (4) a cleansing of the cycle during startup. The condensate bypass loop consists of two precoat-type filters with wedge wire elements, followed by three 10 ft 6 in. diam mixed-bed demineralizers each with its own cartridge-type effluent filter. This section was sized to handle 100 per cent of condensate flow at full turbine load.

The authors showed an illustration of the manner in which the condenser is divided into compartments, each monitored by acid-exchanged conductance, and valved so that they can all be fed to the cleanup loop in case of major contamination or a tube rupture.

A rather detailed description of the chemical cleaning findings were advanced. It was found that system contamination was still considerable at the onset of cycle circulation prior to operation. This meant that the remaining cleanup depended solely upon the bypass purification system. The rate of cycle cleanup was largely a function of demineralizer pre-filter operation. Reduction of suspended matter, which constituted the bulk of the contamination was dependent on filter performance. The lowering of dissolved matter was carried out by ion exchange and its control was established by the rate of flow through the filters to the demineralizers.

During this period the pre-filters plugged up badly and subsequent attempts were made to improve the pre-filter by different materials. By way of contrast the initial differential pressure across them was high, 15 to 20 lb, and even with a pressure differential of 70 lb runs were less than half an hour in length before precoating was necessary. Using the latest, clean elements for June 4, 1960, startup the initial pressure drop was two to four lb and first runs about six hours. June 15, 1960, filter runs were 16 to 20 hr.

In much the same vein the authors dug into the major elements of the water treatment system giving results and operating experiences. One highlight was the condensate bypass cleanup cost. During operation between January 26, 1960, and May 6, 1960, 162 million gallons of water went through the purification system. This was 44 per cent of the total feedwater flow. Actual chemical cost of this cleaning was $1^1/_4$ cents per thousand of gallons bypassed. The authors provided a tabular breakdown. Based on these figures the yearly operating costs would be $700.

The overwhelming factor of the cost was the filter operation. Pre-filter costs ran about one half the total and postfilter about one third. Pre-filter runs averaged only about eight hours. As these runs are lengthened costs should go down. Simultaneously as the cycle is cleaned postfilter costs will drop. Another abnormal factor that increased costs was the six startups in this period.

S. B. Applebaum, Cochrane Corp., saluted the authors and their company for sharing their startup experiences with the industry. He confined his comments to lessons he felt were already apparent. These Mr. Applebaum went through item by item. Points such as the simplification of the makeup plant by omitting polishing secondary units as one of the savings possible with condensate scavenging demineralizers were mentioned. Another was the use of a complete collector system for each probe at the various elevations in the demineralizer bed to monitor conductivity rise and anticipate silica breakthrough which is a most valuable operating tool.

The best results experienced with the least maintenance for the in-line dilution system of regeneration was also noted.

Don F. Aspach, R. P. Adams Co., Inc., confined his discussion to the prefilters. He pointed out that the design of the precoat filters used at Avon was based on 28 weeks of pilot testing with a prototype precoat filter at the station. The condensate used for the pilot test was from the old steam system at Avon and not from a supercritical boiler.

Once in operation it was expected some difficulties would develop. These difficulties are under study and already improvements have been suggested. The prefilter photographs in Mr. Vyhnalek's and Mr. Banks' report illustrate dramatically how the fibrous filter aid became lodged on the inside or bore side of each filter element. Tube fouling on the filtered water side can only be attributed to improper backwash procedure or to contaminated backwash liquid. At Avon it is now obvious that the condensate should not be used to develop the compressed air head in the upper dome of the filter unit. The author's company has taken steps toward a different procedure.

Today with Nerofil filter aid cycles have increased to about 30 hr. Prefilters have fluctuated from an operating time of 8 hr to about 30 hr from June until August 18, the last reading indicating a closer link to system operation rather than filter problems. Studies are under way now to see if the supercritical condensate is introducing variables not present in the pilot plant study condensate.

Nuclear Water Cleaning

The subject "Chemical Cleaning of Boiling Water Reactor and Steam-Water System at the Dresden Nuclear Power Station" made the paper presented by **R. J. Kremer,** Solvent Service, Inc., **A. B. Sisson,** Commonwealth Edison Co., **R. C. Reid,** General Electric Co., and **M. F. Obrecht,** Michigan State Univ.

The primary steam generating circuit which included the reactor vessel, secondary steam generating circuit, primary and secondary feedwater systems, main condenser, and all associated steam and feedwater piping were felt in need of chemical cleaning.

The primary steam generating circuit was cleaned to eliminate suspended materials which could become activated and cause maintenance problems. The primary feedwater system was cleaned to prevent corrosion products from reaching the reactor. The cleaning of the secondary feedwater system, secondary steam generating system, extraction steam system and condenser was not considered as critical as the reactor components, for all condensate flowing to the primary feedwater pumps passed through the condensate demineralizer. These systems were cleaned to reduce demineralizer load.

By IGOR J. KARASSIK*

Worthington Corp.

The boiler feed pump and its associated equipment represent a major operating and maintenance consideration in today's power plant. Here we run in question and answer form a series of clinic sessions on various boiler feed pump problems. The replies are the work of one of the topmost pump authorities and give specific information which we hope will prove valuable to our readers.

Steam Power Plant Clinic—Part XXI

QUESTION

Do you recommend as a satisfactory arrangement the use of two half-capacity boiler feed pumps, of which one would be operated at constant speed and the second one at variable speed by means of a hydraulic coupling? This second pump would then take up the load fluctuations. Would the same spare rotor be suitable for both pumps, allowing for the slip of the coupling?

ANSWER

I understand that a few such installations have been made and, of course, they can be made to work, Fig. 1. Nevertheless, I am definitely not in favor of such a set-up. The savings correspond to the initial cost of the variable speed device. Against this we must weigh a number of unfavorable factors. The system still requires the use of a feedwater regulator and its cost and maintenance must be charged against this arrangement. The total flow will not be split up evenly between the two pumps and the variable speed driven pump will always carry a much lesser portion of the load than the constant speed pump. Thus, while this latter will be operating in the range of its best efficiency, the variable speed pump will operate at lower efficiencies than it would were the load to be shared equally. As a result, full advantage will never be taken of the variable speed operation.

The variable speed pump will operate at approximately 2 to 3 per cent lower speed than the constant speed pump because of the slip in the hydraulic coupling.

If a spare rotor is purchased and if both pumps are provided with the same impeller diameter, the variable speed pump will have a lower head-capacity curve at its rated speed than the constant speed pump. This would further aggravate the poor distribution of load between the two pumps. It would also introduce difficulties in starting up the variable speed pump whenever the constant speed pump was running alone at very low flows, since the variable speed pump could not develop sufficient pressure to lift its check valve.

As a result, the two pumps should be designed to develop identical head-capacity curves, each at its own rated full speed. This would require the variable speed pump to be built with impellers 2 and 3 per cent larger than the constant speed pump. The same should be true of the spare rotor which must be capable of developing the design head and capacity regardless of which pump is to be rebuilt with it. If, then, the spare rotor has maximum diameter impellers, it will produce from 4 to 6 per cent more head if placed into the constant speed pump. The alternative is to cut these impellers when so using the rotor. This adds to the cost and time and renders the rotor no longer suitable for use with the variable speed pump.

All in all, I can see no sufficient justification for this arrangement. If variable speed drive can be justified, it will generally be justifiable for both pumps. If load conditions and evaluation methods cannot justify two hydraulic couplings, putting in only one seems to be a wasteful and complicated compromise.

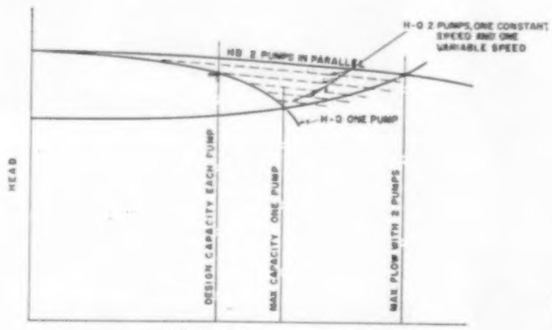


Fig. 1—Operation of two B. F. pumps in parallel, one at constant speed and one at variable speed

* Consulting Engineer and Manager of Planning, Harrison Div.

QUESTION

I would like to have your opinion in connection with the operation of a 125,000 kw reheat unit at light loads of the order of 10 per cent during the night and over week ends. Is it possible to operate at this load without incurring serious trouble at the condenser, deaerator and boiler feed pumps? If the plant has to operate at this load for economical reasons (because of the hydroelectric supply available) would you recommend a complete shutdown or would you run at this 10 per cent load? And if you recommend the latter, would you please suggest operating procedures which would guarantee the minimum of trouble? (*K. F.*)

ANSWER

When we look at a steam power plant, we can classify the equipment it includes into three major groups (as in Fig. 2), identified by the three basic functions which these groups perform in the plant. These are:

1. The Steam Generating Group.
2. The Electric Generating Group.
3. The Fluid Handling Group.

This third group includes the condenser, circulating pumps, condensate pumps, the vacuum producing equipment (ejectors or vacuum pumps), the deaerating heater and the boiler feed pumps. Frankly speaking, the decision on whether to shut a unit down each night and on week ends or to run it at 10 per cent load does not hinge on the problems that arise from low load operation in connection with the Fluid Handling Group equipment, but rather on the economic considerations and practical problems of frequent shutdowns and restarts in the Steam Generating Group and the Electric Generating Group. I do not profess to be sufficiently well versed in all the problems that affect these last two groups, but I have no doubt that power plant operators have very sound reasons against such shutdowns. The major consideration of a utility is the ready availability of such an important block of power as 125,000 kw. As a matter of fact, it is exactly when a system has a large hydroelectric component that a number of steam units in the system may be kept running at extremely low loads, not only at night but sometimes around the clock, on what is called "spinning reserve."

A second consideration, of course, is the decided risk of serious corrosion problems which would be encountered in the major pieces of equipment if the unit were to be shut down so frequently.

As far as the Fluid Handling Groups equipment is concerned, there are several specific areas which require careful attention during extended light load operation.

First, with regards to the condenser, it must be remembered that it will not provide as good deaeration as it does at higher loads. There are several factors which contribute to this reduced efficacy in deaerating the condensate:

(*a*) With so much less steam entering the condenser, most of the steam will have been condensed before it can reach the lower portion of the condenser where efficient deaeration can take place.

(*b*) The absolute pressure in the condenser at 10 per cent load is reduced appreciably below normal load conditions. This is not an unmixed blessing, as the volume of the air-vapor mixture that must be handled by the ejector increases with this decrease in absolute pressure. The ejector, generally, cannot be designed economically to handle this increased volume and the degree of deaeration achieved suffers.

This is a less critical effect in an open feedwater cycle where deaeration is completed in the deaerating heater than in a closed cycle, where the entire deaeration takes place in the condenser.

Precautions are necessary to provide more flow through the condensate pump than just the amount of steam reaching the condenser and proceeding to the hotwell after condensation. This is because the condensate is used as a cooling medium in the ejector inter- and after-

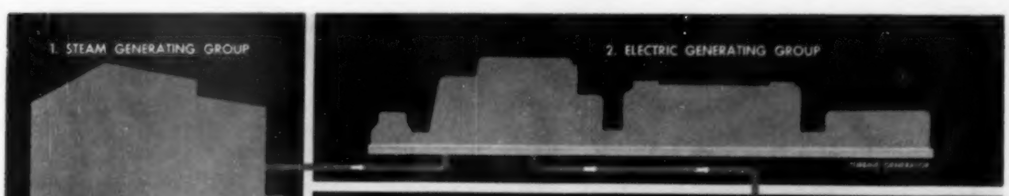


Fig. 2—The three basic components of a steam power plant

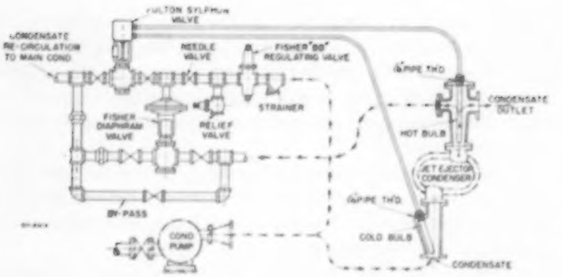


Fig. 3.—An example of an automatic thermostatic valve to control recirculation of condensate

condenser. It is therefore necessary to allow a certain amount of recirculation of the condensate from downstream of the after-condenser back into the hotwell. Many installations are provided with automatic thermostatic controls to achieve this effect, as shown in Fig. 3.

Because the steam flow through the ejector is practically constant, the rise in temperature of the condensate between the inlet and outlet of the ejector condenser is a close indication of the rate of flow of condensate through the ejector condenser tubes. This temperature differential can therefore be used as an impulse to regulate the rate of flow of condensate through an automatic device.

As shown in Fig. 3, a small pipe is connected from the condensate outlet on the ejector condenser back to the main condenser shell. An automatic valve is installed in this line, actuated and controlled by the temperature rise of the condensate. Whenever the temperature rise reaches a predetermined maximum, indicating a low flow of condensate, the automatic valve begins to open. This allows some of the condensate to return to the main condenser and maintains the flow from the condensate pump at the required minimum value. As long as the temperature rise through the ejector condenser is less than the limiting amount, indicating that ample condensate is flowing through the ejector condenser, the automatic valve remains closed.

This recirculation is equally important if vertical "can" type pumps are used, as these are not as suitable for extremely low flow operation as the conventional horizontal condensate pumps.

If two circulating pumps are provided, it is logical to shut one of these down during light load operation to save power. Of course, with two pump installations, it is usual to run both in summer and one in winter.

The effect of low load operation on the deaerating heater will vary somewhat, as some designs are not affected by this in so far as deaeration is concerned, while others are. The only possible additional precaution that might be suggested is to provide some auxiliary heating means for the deaerating heater storage, either in the form of steam heating coils or through electric heating. If the deaerating heater is designed for 10-minute storage under normal conditions, this storage volume corresponds to 100 minutes supply at 10 per cent load—almost two hours. Operation at very light loads for extended periods of time may lead to cooling the heated storage feedwater to below saturation. If auxiliary heating means are provided, there will be less chance of reabsorbing oxygen in the stored feedwater.

Another cautionary suggestion deals with the operation of the vents in the deaerating heater. Some operators manipulate the valves in the vent lines under the impression that throttling the venting at light loads reduces loss of steam and, hence, improves the heat balance. This is quite debatable, because the deaerating heater of large units will normally "float" on a turbine extraction stage and heater pressure varies almost directly with the load. Consequently, the vent orifice is essentially proportioned for a wide load range since the pressure differential available for venting varies with the load. But should the valves in the vent lines be throttled during light load operation, the danger exists that they will be left that way through oversight when the load builds up and the venting will be inadequate.

Of course, the boiler feed pump is quite vulnerable to light load operation. First, we know that a pump operating frequently at loads other than in its best efficiency range will not have as long an operating life between overhauls as it would otherwise. This, however, is part of the price one has to pay for requiring light load operation in the steam plant. If full load conditions are met with two pumps operating in parallel, one of the two pumps should be shut down—both to conserve power and to improve the operating conditions of the pump which remains on the line.

But the most important problem is that of protection of the boiler feed pump against overheating during this low flow operation. Of course, no modern 125,000 kw unit is ever installed without automatic bypass recirculation controls. It is imperative, however, to assure oneself that these controls are in good operating condition and that no danger exists of operating the pumps against full shut-off or with too high a temperature rise.

Molten Salt Reactor Experiment at Oak Ridge

A reactor experiment of the molten salt type will be constructed at the Oak Ridge National Laboratory to investigate advanced reactor concepts having potential advantages for production of electrical power.

Design of the reactor, to be known as the Molten Salt Reactor Experiment (MSRE), currently is under way by ORNL with some assistance by personnel from Burns and Roe, architect engineer firm of New York City. Oak Ridge National Laboratory is operated by Union Carbide Corporation for the United States Atomic Energy Commission.

The major objectives of the MSRE are to demonstrate the dependability, serviceability, and safety of the molten salt reactor concepts for civilian power purposes, providing confirmation of earlier experimental work and information on components needed for a larger reactor. The molten salt reactor concept offers the potential economic advantages of excellent steam conditions and higher efficiency through operation at very high temperatures and specific power. Since the fuel is in solution, no fabrication of fuel elements is necessary and continuous removal of fission poisons is possible.

By D. N. HIGGINS*

BROWN AND ROOT, INC.

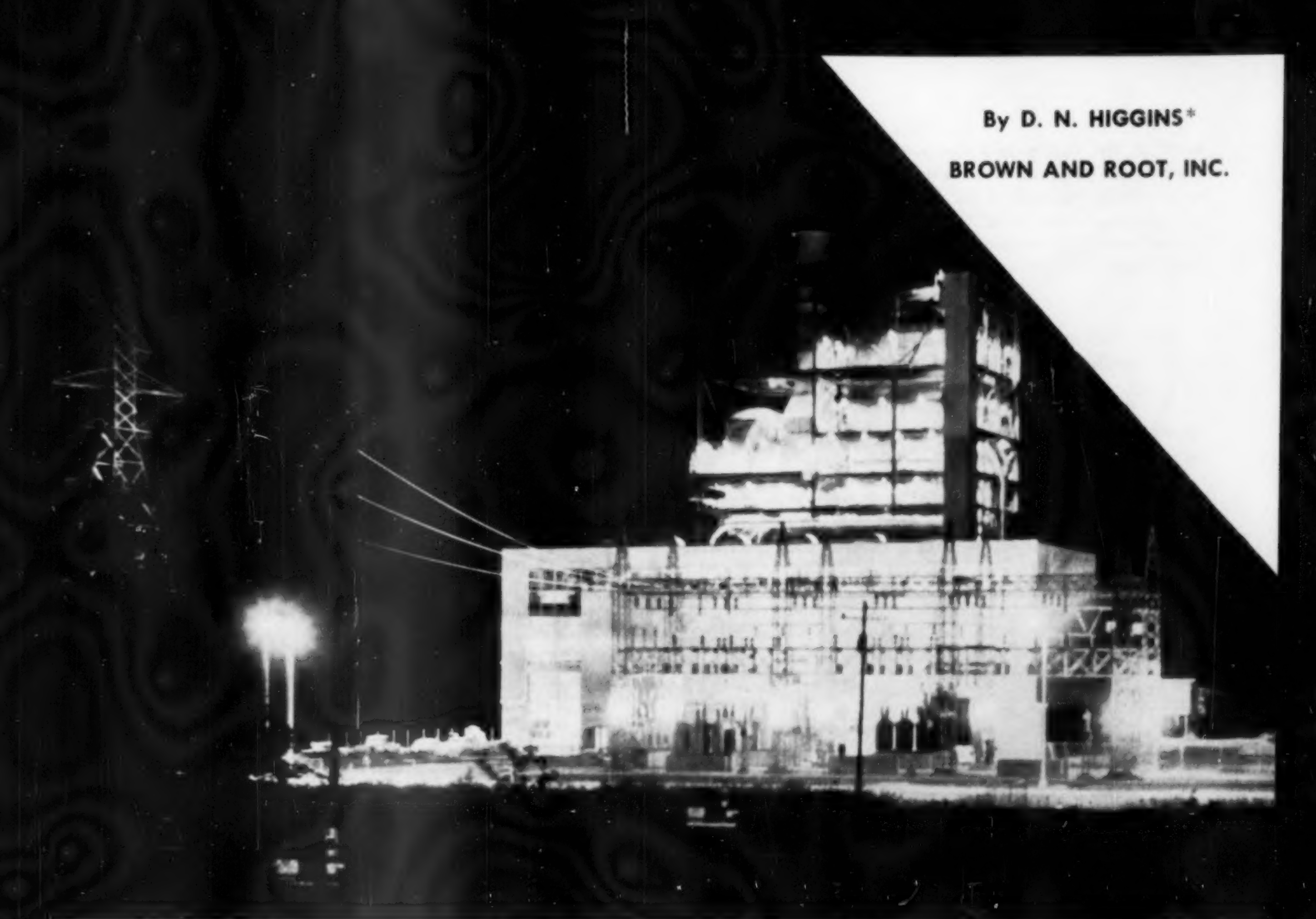


Fig. 1—Dramatic view of City of Austin's Holly Street Station

115 Mw Semi-outdoor Reheat Station Costs \$82.12/Kw

Mr. Higgins details the requirements for a successful installation at City of Austin's Holly Street Station. Qualified engineers for design and supervision, an experienced constructor bidding on a lump sum basis and outstanding coordination between owner, engineer and erector are factors he insists upon. Results speak for themselves—one of the lowest per kw costs in the Southwest, minimum plans-to-operation time and a short, trouble-free start up.

ELECTRIC energy requirements in the Austin, Tex., area are rapidly increasing. Annual increase is approaching fourteen per cent per year. Because of this load growth and because of a gradual expansion of load center, a new plant that had been in the planning stage has now become a reality. This station is at a new location and its ultimate capacity will exceed four hundred thousand kilowatts.

Several possible plant locations were available along the Colorado River where ample circulating water was available for the ultimate capacity. All of the locations would be subject to possible flooding from river bank overflow under extreme weather and climate conditions and all presented the same design problems. The area finally chosen was a twelve acre site, located on the west

* Chief Power Engineer.

bank of the Colorado River within the City of Austin limits and adjacent to a residential section. The site was selected because of its proximity to the 69 and 138 kv systems connecting the two older plants and the interconnecting outside utility. Transmission lines are very short and costs and losses are at a minimum.

Holly Street Station

Holly Street Station will ultimately consist of four units, located in line leading away from the river bank (Fig. 2). Plant was planned for simplicity and low unit cost. Station design is semi-outdoor. The turbine-generator and electrical equipment is housed in a modern steel and concrete building. Unit No. 1, Fig. 3, is now in operation and consists of a single 100-mw reheat turbine-generator and boiler rated at 800,000 lb of steam per hour. Steam pressure is 1525 psig at throttle and 1000/1000 F total temperature. Unit gross capability is in excess of 115 mw and station auxiliaries require

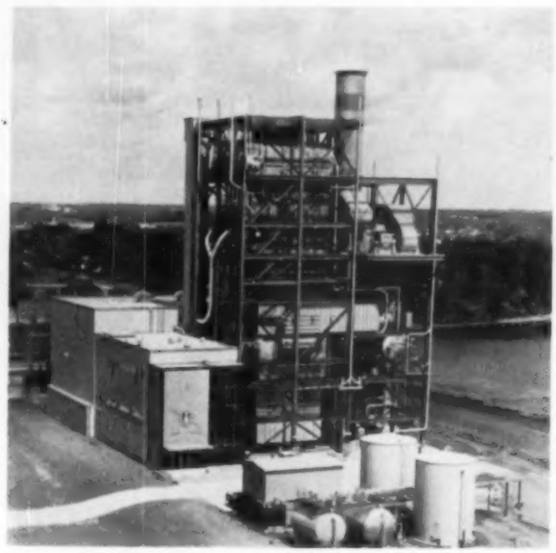


Fig. 2—Holly Street Station by daylight. Area to the left remains open for addition of 3 more units in line leading away from the river

3.9 mw. Boiler is gas fired with light fuel oil standby. Careful consideration was given to outdoor vs. semi-outdoor construction and after all factors were considered the semi-outdoor design was selected. Boiler, feedwater heaters and forced draft fans are outdoors. Forced draft fans are located at air preheater elevation, 80 ft 9 in above grade, to minimize duct work, provide clean air and reduce noise. Deaerating heater is supported on the boiler steel under the air preheater and three of the stage heaters are at grade under the deaerator. This uses space normally taken up by fans and duct work, eliminates a feedwater heater bay and still provides sufficient head on the boiler feed pumps from the deaerator under all operating and transient conditions. The first-stage heater is located in the condenser neck. Two half-capacity boiler feed and two full capacity condensate pumps are used instead of three half-capacity units. Operation has shown that the use of only one feed pump, one forced draft fan and one circulating pump will produce 75 mw. Circulating pumps are located in intake and screen structure designed for flood protection and are vertical mixed-flow rated at 32,500 gpm each when operating in parallel at 30 ft total discharge head. Water temperature from river does not exceed 80 F. Circulating water to and from condenser is carried through centrifugally cast concrete pipe 60 in. in diameter. Because of river water conditions during dry spells, condensers are two-pass divided water box and have 65,000 sq ft surface. Intake structure is designed to have adequate head on circulating pumps during extreme low water conditions.

Make-up water is from a demineralizer sized for two 100-mw units. Water supply to demineralizer is from City water system. Two storage tanks are provided, one for condensate and one for demineralized water. The value of this was proved during initial start-up. All lines, condenser pumps and heaters, in fact the entire feedwater system and boiler, were cleaned with demineralized water before start-up. Demineralized water was used for initial firing of boiler and blowout of main steam and reheat lines. After steam was turned into the unit for the first time, it was brought to full load without ever stopping the unit. During this operation silica in the boiler water never exceeded 3.6 ppm.

Steam cycle is conventional with five feedwater heaters including the deaerator which is in the number three position. Make-up water is introduced at the condenser for partial deaeration. Heater drains are cascaded from No. 2 heater to No. 1 and also to the condenser through integral drain coolers. Drain control for the closed feedwater heaters Nos. 2, 3 and 5 is an orifice in lieu of the conventional control valve. This arrangement has proved very satisfactory throughout all load ranges. Up to 100 mw, the unit normally operates at throttle pressure of 1450 psig and temperatures 1000/1000 F with a turbine heat rate of 8079 Btu per kilowatt-hour. Above 100 mw, the unit operates at 1525 psig and 1000/1000 F total temperature. Turbine heat rate increases slightly to 8089 Btu per kilowatt-hour under these overpressure peaking conditions.

Station Building

Station building including turbine-generator bay, office and control room sections are designed to withstand flood conditions 14 ft above finished grade elevation. The entire plant is supported on poured-in-place concrete piles extending to rock. Site required 140,000 cu yd of fill taken from the river when excavating and clearing out the river bed for intake and discharge water structures. The concrete structure extends 14 ft above grade for flood protection, all openings such as doors are designed to prevent water leakage into the building. In addition, the entire structure was provided with sufficient mass to prevent floating under the highest recorded flood.

Building contains 7.88 cu ft per kilowatt. Control room is located at the boiler firing platform elevation. Office space is also at the same level and is behind the control room. Building walls above concrete are of insulated metallic construction designed to give the turbine room not only an attractive interior finish but a combination of thermal and acoustical insulation as well.

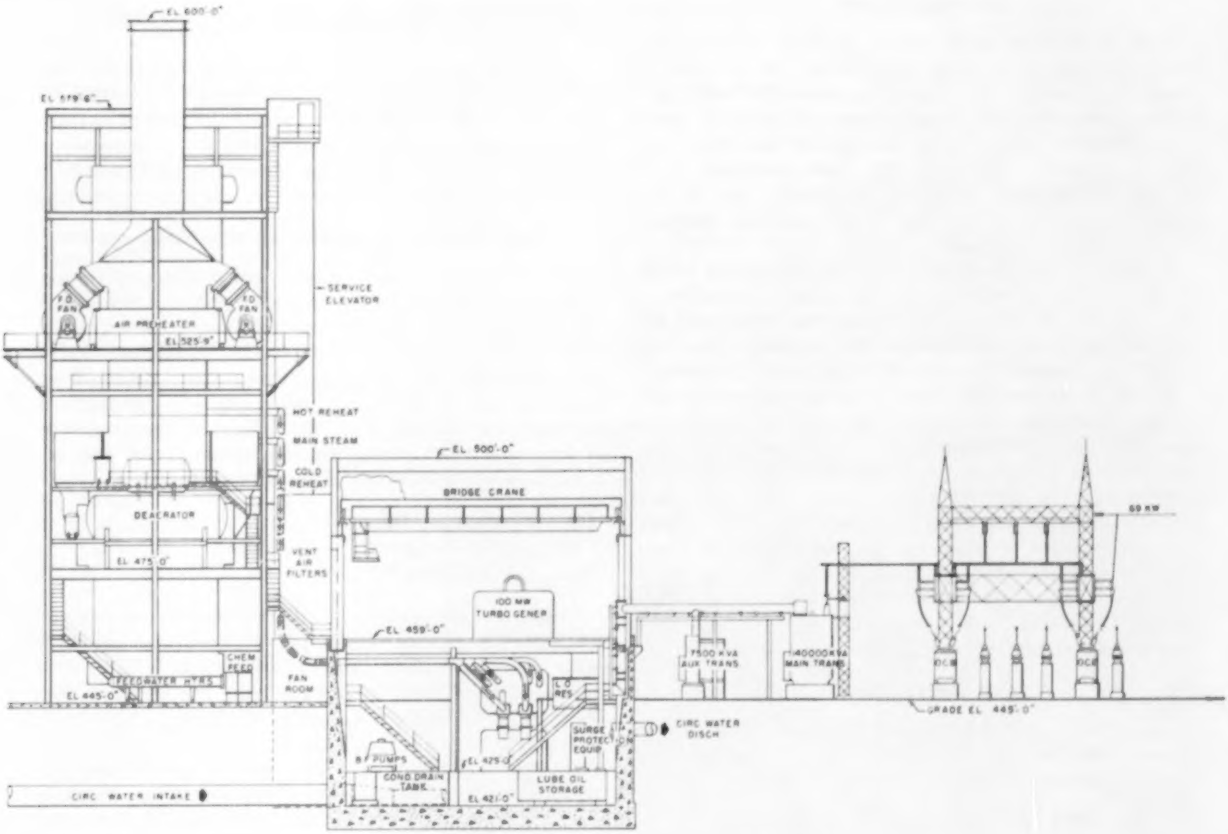


Fig. 3—Sectional elevation showing arrangement of equipment

The colored siding of the plant actually forms a curtain wall around the turbine room. The exterior sheet consists of 24-gage V-beam siding of asbestos-protected metal, factory finished to selected color. The interior sheet consists of 18-gage zinc coated steel painted to match interior finish. Every other one of these interior sheets is perforated to increase the acoustic character of the wall surface.

The ceiling of the turbine room is acoustically treated under a $2^1/_2$ in. light-weight insulating concrete slab. The ceiling has a 1-in. acoustic board covered with perforated corrugated zinc-coated steel; while the walls have $1^1/_2$-in. thick glass fiber insulation.

Building steel provides support and runway for the 150-ton crane to handle the heaviest parts of turbine-generators during erection. Turbine bay is 149 ft long by 69 ft wide and includes railroad track bay. Control room office bay is 35 ft wide by 77 ft long. During construction and erection of equipment there was generous space for all operations.

Controls and Instrumentation

The control room, manual feedwater and fuel gas controls, burners and boiler start-up panel are all at the same elevation. Boiler, turbine, generator, spare exciter and turbine supervisory instruments are all mounted on one control board. Control system for the boiler is a standard conventional metering type with 3-element pressure compensated feedwater control system. Interlock devices were incorporated with the combustion control system for damper actuation of single or two-fan operation.

Combustion controls are designed for gas or oil firing in combination or individually, with oil firing by remote manual operation from control panel.

Superheat steam temperature control is by means of water spray with combustion air flow signal in parallel with temperature transmitter.

Reheat temperature control is same as superheat, except control output is split range to burner tilts and spray valve in sequence.

Interlock system design safeguards the boiler by an automatic purge cycle when required conditions exist and forced draft fan is started. Boiler ignition is local with remote automatic trip from turbine or manual trip from BTG panel.

Spring and remote actuated gas minimum burner pressure control valve is incorporated in design for boiler start and minimum flame control. Bench front duplex panel in control room incorporates control switches for motors, giving operator control of unit auxiliaries from control room, generator control switches are also located on same panel. Local panels are installed for information and control at burner level for boiler start; turbine level for turbine start; basement for feedwater, condensate; and river intake station.

Electrical System

Main leads from generator to 3-phase, 140,000-kva, FOA, 13.2–69 kv step-up transformer are of isolated phase construction with taps to generator surge protection and potential transformers in isolated phase compartments located under the bus at basement level and to 3-phase, 7500 kva, OA, unit auxiliary 13.2–2.4 kv transformer located immediately outside the building. A 69,000 to 2400 volt standby auxiliary transformer is also provided.

A spare exciter motor-generator set is located at the generator end of the mezzanine level. Adjacent to this unit is the excitation switchgear. Provision has been incorporated to transfer the regulator from the main to the spare exciter directly from the BTG board.

Twenty-four hundred (2400) volt switchgear, located in the switchgear room under the control wing at the operating floor level, supplies the larger auxiliary motors and 480 volt power center which feeds 480 volt motor control centers for other auxiliaries. The generator and its auxiliaries are controlled from the boiler-turbine-generator board located in the main control room. Control and protective relaying for 69 kv feeders is from line control panel also located in the main control room. Overhead cable trays are used to the greatest possible extent for routing of control and power cables.

Station Cost

The total central station project covers all components required for the unit 100 mw system and also includes, by category, the following additional items.

(1) Site Area Development for Four Units
Fire protection system, roadways, parking areas, yard lighting and fencing

(2) Electrical
Station start-up transformer for four units, main step-up and auxiliary transformers, 69 kv step-up substation, spare exciter for two units, and supervisory control microwave equipment

(3) Storage
35,000 bbl underground oil storage tank and tank car unloading facilities

(4) Circulating Water
Condenser circulating water discharge structure and lead piping for four units.

(5) Water Treatment
Demineralized water treating plant and storage tanks for two units

(6) Building
Air conditioned control room and plant offices for two units, full capacity crane for lifting generator stator.

(7) Miscellaneous
Owner's administrative expenses, land cost.

Total cost of the project to date is $10,648,210. On the basis of 115 mw capability, cost at the completion of Unit No. 1 is $92.59 per kw. Cost of the project chargeable to the generation system of Unit No. 1, in accordance with FPC Uniform System of Accounts, is $9,443,371. Based on 115 mw capability this cost is $82.12 per kw.

Engineering—Construction—Initial Operation

Brown & Root, Inc., was awarded the engineering contract on June 6, 1958, and on August 15, 1960, Unit No. 1 was ready for commercial operation. All drawings, specifications, conduit and cable schedules, valve and material lists, and instrumentation detail were complete for lump sum single contract construction bidding on March 1, 1959. Engineering contract covered the engineering services required for the accomplishment of this type of project including:

A. Preliminary Phase
B. Design Phase
C. Construction Phase

Construction contract for all work was awarded to the qualified constructor on competitive bids in accordance with complete plans and specifications. Bids were received on a lump sum basis and the contract was awarded accordingly and with no escalation. Construction started April 1, 1959, and steam was turned into the turbine-generator on July 26, 1960. Construction was under the general supervision of engineers from Brown & Root, Inc., through routine visits to the job for personal observation of the work and consultation with Customer's resident engineer.

The plant start-up and initial operation was under general supervision of Brown & Root engineers. This work was completed in a period of one week, with steam admitted to turbine throttle on July 26, 1960, and the system brought down for routine check on August 2, 1960. During this period the system was operated at 105 mw for a period of approximately 20 hr. Throughout this phase we encountered no unusual problems.

The cost per kw of this new semi-outdoor station is among the lowest costs in the Southwest for gas-fired plants of any capacity. Close cooperation of the Owner, the manufacturers of the equipment, the construction contractor, and the Engineers helped to make this low unit cost possible. The total time between award of engineering contract and initial operation, twenty-six months, is also a considerable factor in low total cost and is a direct result of this effective liaison.

AEC, Bu Mines Gas Recycle Completes 1000-hr.

An advanced helium gas recycle system, developed jointly by the Department of Interior's Bureau of Mines and the Atomic Energy Commission as a step toward possible utilization of nuclear heat for industrial processes, completed 1000 hr of continuous operation at design conditions on October 22, 1960.

The system, designed to study the technical feasibility of providing nuclear heat for high-temperature industrial processes—including the gasification of coal—had operated continuously for more than 41 days at a gas temperature of 2500 F and a pressure of 250 lb per-sq-in. before it was shutdown for routine inspection. The experimental facility is located at the Bureau of Mines' Coal Research Center at Morgantown, W. Va.

The Morgantown gas recycle system is powered by induction heaters which simulate a high-temperature nuclear reactor. The system includes heat exchangers, compressors and other components essential to a commercial high-temperature nuclear process heat system.

Abstracts from the Technical Press—Abroad and Domestic

(Drawn from the monthly Technical Bulletin, International Combustion, Ltd., London, W. C. 1)

Fuels: Sources, Properties and Preparation

Chemical Structure and Properties of Coal XXVII—Composition and Molecular Weight Distribution of Coal Extracts. H. N. M. Dormans and D. W. van Krevelen. *Fuel* 1960, **39** (July), 273–92.

The Dependence of the Swelling Pressure on the Temperature Conditions during Coking. W. Radmacher and H. L. Marié. *Brennst-Chemie* 1960, **41** (June), 166–70 (in German).

Since the various methods for the determination of the swelling pressure in the laboratory give very different results a new method has been developed in which the coal sample is inserted into a hot coking crucible. The temperature and rate of heating can be varied so that studies of the influence of rate of heating and coal rank on swelling pressure could be carried out which faithfully represented the results of full-scale plants. It could be shown that the swelling pressure and drum strength are dependent on the heating conditions.

Laboratory Investigations into the Behaviour of Salt-Coal Ash in Steam Generators. K. Wickert. *Energie* 1960, **12** (June), 240–6 (in German).

The behavior of the different constituents of brown coal ash with high contents of highly volatile sodium compounds (up to 25 per cent) and high S content was studied as a function of temperature, flue gas composition and additives. Conclusions are drawn with regard to the probable deposit formation in furnaces with dry and wet ash removal.

Mechanical Handling

New Means of Transport in the European Energy Distribution. H. Winkhaus. *B.W.K.* 1960, **12** (June), 238–43 (in German).

An attempt is made to assess the limits within which transport of solid, liquid and gaseous fuels by pipeline would be economic. Several projects in operation, under construction and in the planning stage are discussed.

Steam Generation and Power Production

Experimental Determination of the Specific Heat of Heavy Water. S. L. Rivkin and B. N. Egorov. *Kernenergie* 1960, **3** (June), 582–4 (in German).

The results of Russian investigations are reported for temperatures up to 300 C and pressures up to 100 kg/cm².

Experimental Determination of the Thermal Conductivity of Heavy Water. N. B. Vargaftik, O. N. Olescuk and P. E. Beljakova. *Kernenergie* 1960, **3** (June), 585–7 (in German).

These Russian studies were carried out in the range of pressures from 1 to 208 kg/cm² and temperatures of 25–360 C.

Strength Behaviour of Thick-Walled Hollow Cylinders under Inside Pressure in the Fully Plastic Range. Studies by Bursting Tests. K. Wellinger and D. Uebing. *Mitt. V.G.B.* No. 66, 1960 (June), 134–48 (in German).

Bursting tests on thick-walled hollow cylinders in a specially developed

test rig allowing application of pressures up to 8000 kg/cm² are reported. From the results the maximum permissible pressure can be calculated.

Calculation of the Laminar and Turbulent Pressure Drop at a Pipe Inlet. N. Scholz. *Chem Ing. Tech.* 1960, **32** (June), 405–9 (in German).

Simplified equations have been developed for the calculation of the laminar and turbulent flow at a pipe inlet; the results agree well with the strict theory and measurements. The transition from laminar to turbulent flow is also treated and suitable equations are presented.

Present State of Steam Generator Technique. Oil Firing in Steam Generators in Western Germany. H. Richter. *Mitt V.G.B.* No. 66, 1960 (June), 155–8 (in German).

Statics of numbers of boilers, year of erection, pressure and temperature ranges, outputs, combinations with other fuels and of coal, brown coal, oil, gas and multifuel fired boilers.

Firing of Low-Grade Fuels and of Different Fuels in a Single Plant. Wasserrohrkessel-Verband and T. Geissler. *B.W.K.* 1960, **12** (June), 257–66 (in German).

Boilers designed for the firing of low-grade bituminous coal, coke and coke breeze, brown coal and lignite, peat, oil, waste wood, blast furnace and coke oven gas either singly or in different combinations are described with special attention to the high efficiency obtained in their operation.

The Russian PK-33-83 SP High-capacity Once-through Boiler. Z. G. Model. *Energomashinostroenie* 1960 (April), 1–7 (in Russian).

The layout, components and fundamental design philosophy of the Russian 650 *t/h*, 1060 F/2060 psi (reheat to 1060 F/400 psi) once-through boiler are examined.

From, *C.E.G.B. abstract*,

Prefab Coal-Fired Boiler Wins Out in Navy Tests. L. F. Deming. *Pwr. Engng.* 1960, **64** (June), 82–4.

Two sizes of packaged boiler designed for rapid conversion from oil to coal and vice versa were tested. The smaller one for 12,000 lb/hr was fitted with a longitudinal drum, spreader stoker and vibrating grate overfire air from the front and cinder reinjection at the sides and rear (through the bridge wall), I.D. and F.D. fans and low-draught loss dust collector. At an average rate of 12,994 lb/hr the thermal efficiency was 85.31 per cent. The larger size has two transverse drums, a spreader stoker with oscillating grate and is rated at 30,000 lb/hr. In tests on oil efficiencies of up to 88 per cent were reached but combustion was incomplete and carbon deposited in the dust collector. In tests with a variety of coals efficiencies between 78.7 and 84.95 per cent were obtained. Further tests were carried out with lignite when the thermal efficiency reached 75.6 per cent.

Liquid and Gaseous Fuel Firing

Pressurised Oil Burners for Steam Generators. Pt. I. G. Weber. *Mitt. V.G.B.* No. 66, 1960 (June), 164–78 (in German).

A detailed theoretical analysis of oil atomization is followed by a description of the application of the theory to the design of various types of burners and their control. Volume and pressure of combustion air and their control are also discussed.

Water Treatment

New Specifications for the Silicic Acid Content of Boiler Water. H. E. Hömig. *Mitt. V.G.B.* No. 66, 1960 (June), 158–63 (in German).

The necessity for new specifications based on the latest scientific studies is explained and recommendations made for new values of the SiO_2 content of boiler waters for pressure up to 80 atu and from 80 atü upwards. The new values can be taken from two graphs.

Heat Recovery Plant

Here's a Unique Industrial Soot-Blower Installation. W. Bois. *Pwr. Engng.* 1960, **64** (June), 88–9.

In an oil fired boiler rated at 40,000 lb/hr at 400 psi and 600 F a conventional rotary sootblower was used to clean the tube banks above the burners. After several years this was completely burned out and then replaced by a retractable sootblower oscillating 165 deg installed below the tube banks using steam at 100 psi as medium. The oscillating type was chosen so as not to interfere with the combustion and flame below. The oscillation of the motor was obtained by fitting limit switches. A second motor advances and retracts the lance. Because of the more efficient cleaning due to the oscillation sootblowing is now necessary only once per 24 hr.

Power Generation and Power Plant

American Power Conference in Review—II. Anon. *Combustion* 1960, **31** (June), 48–54.

The second part presents abstracts of paper on condensers, fuels, control of oil and gas burners and large steam turbines.

Technical Trends in Steam Power Stations. Anon. *Techn. Mod.* 1960, **52** (May), 284–90 (in French).

The development since 1921 is traced and several tables show the progress made in 40 years with regard to efficiency, reduction in personnel and capital costs.

The Direct Generation of Electricity —2. B. C. Lindley. *Nucl. Pwr.* 1960, **5** (July), 80–3.

The second part deals with magnetohydrodynamic generation and the fuel cell.

How Coal Can Fuel the Turbo-Charged Steam Plant. J. L. Yellot. *Pwr. Engng.* 1960, **64** (June), 68–70.

Various possibilities of using coal as fuel in a combined gas and steam turbine plant are discussed: (1) Partial gasification; (2) total gasification; (3) direct coal firing under high pressure.

The Typical Power Station of 600 MW. S. Kowallik. *Energietechnik* 1960, **10** (June), 239–48 (in German).

For the typical new power station of the German Democratic Republic steam generators are rated at 350 t/h, 135 atü and 530 C. They will contain swirl burners high up in the furnace front wall so that the gas flow is downward in the furnace, upward in the 2nd pass containing evaporator and superheater tube platens and downward again in the convection pass. Possibly also boilers with opposed burner ring will be installed later. Because of the high S content of the brown coal (2.5–3 per cent) the air will be preheated by steam to at least 80 C before entering the air preheater to prevent corrosion and clogging. The description includes the heat flow diagram, layout, coal and ash handling plant, turbines and generators, pipelines, feed water treatment, controls and treatment of cooling water and electrical installations.

The Chalon II Power Station. F. Scheurer. *Techn. Mod.* 1960, **52** (May), 272–83 (in French).

This power station has been built to utilize mainly Blanzy coal with an ash content of up to 45 per cent, V.M. content of up to 33 per cent and a moisture content of up to 11 per cent. Because of the high ash content boilers with four cyclone furnaces have been chosen which supply 125 Mw turbogenerators.

The Steam Power Station at Champagne - Sur - Oise. M. Mascarello. *Techn. Mod.* 1960, **52** (May), 260–3 (in French).

This is one of the first French power stations in which a 250 Mw unit is being installed. Steam is generated at 141 atü and 565 C with reheat to 565 C, a feedwater temperature of 260 C and a flue gas exit temperature of 120 C. The calculated net heat rate is 2240 kcal/kwhr.

The Brown Coal Power Station "Citta di Roma." Anon. *Energie* 1960, **12** (May), 219 (in German).

This power station 20 miles south of Perugia utilizes brown coal with an average C.V. of 2340 Btu/lb in two Benson outdoor boilers each rated at 270 klb/hr at 2060 psi and 986/975 C and two 36 Mw turbogenerators. Each boiler is supplied from 4 mills with an individual output of 23 t/h. Electric power is transmitted to Rome at 158 kv over a distance of 94 miles.

The Lacq-Artix Power Station. F. Scheurer. *Tech. Mod.* 1960, **52** (May), 241–5 (in French).

This power station is being constructed to supply energy to a new aluminum producing factory. It will contain four units of 125 Mw capacity, each supplied by natural gas fired boilers rated at 360/400 t/h at 140 atü and 542 C with reheat to 542 C; the flue gas exit temperature at the air preheater is 110 C.

The Recovery of Expansion Energy at the Artix Power Station. H. Lescoeur. *Techn. Mod.* 1960, **52** (May), 246–51 (in French).

The gas is supplied to this station at a pressure of 568 psi and a temperature of 10 C. The gas is preheated to 350 C and then passed through a gas turbine generator of 3500 kw capacity in which the pressure is reduced to 31.3 psi at a temperature of 150 C before it is supplied to the burners of the boilers. The gas is first heated by exchange with feedwater and then by steam.

Conversion of the Nantes-Cheviré Power Station to Natural Gas Firing. T. Mabilleau, M. Delorme and R. Liebray. *Techn. Mod.* 1960, **52** (May), 264–9 (in French).

The modifications necessary for firing natural gas in boilers previously fired by coal and oil are described, especially with regard to the automatic controls for firing each fuel alone or in any combination.

Portishead "B" Power Station. Anon. *Petrol. Times* 1960, **61** (June 17), 423.

Boilers 8–12 in this station were supplied with retractable corner burners and despite high turbulence of the flame no impingement of it on the wall has occurred. The air to the burner is subdivided into primary, secondary and tertiary air to obtain optimum atomization and complete

burning out of the 6000 sec. Redwood No. 1 oil with an S content of 4–4.7%. No acid corrosion or smut emission has occurred, the average efficiency has been 85.5 per cent and the availability 96 per cent.

The St. Andra II Steam Power Station, Austria. Anon. *Ö.Z.E.* 1960, **13** (April), 102–184 (in German).

The issue is devoted to articles dealing with the station, which has a 330 t/h, 207 atm. (gage), 530 C Benson boiler, with reheat to 530 C, and a 125 MVA hydrogen-cooled turbo-alternator. Cost was approximately £42/kw.

From *C.E.G.B. Digest* 1960, **12** (July), 1720.

How We Modernized Our Plant and Saved Money. M. Buhner. *Pwr. Engng.* 1960, **64** (June), 74–5.

At the Fox River Paper Corp. it was found possible to install new plant and operate it at a much lower cost than estimated by consultants. The new boiler is rated at 40,000 lb/hr and fitted with a Vibra-Grate stoker including automatic combustion controls and a pneumatic ash handling system; no new buildings or foundation work was required. The new plant is operated by four shift men and one utility man on the day-shift, i.e., not more than would have been required by an oil-fired boiler.

Benson Boiler at Steelworks. Anon. *Elec. Times* 1960, **137** (June 16), 961–3.

The new plant recently completed at the Margam Steelworks consists of a three-pass semi-outdoor Benson boiler (240 klb/hr) and a 9.5 mw back-pressure turbogenerator. The steam is generated at 3300 psi and 1060 F and the turbine exhaust steam reheated to 836 F before being passed into the existing 625 psi mains. The main fuel is blast furnace gas with oil as standby. Combustion control is obtained by control of the F.D. fans as a function of the fuel supplied to the furnace.

Extensions to Power Plant at the Mersey Mill of the Bowater Paper Corp. Ltd. Anon. *Pwr. & Wrks. Engng.* 1960, **55** (June), 444–9

The new extension comprises three spreader-stoker fired boilers each rated at 90 klb/hr at 925 psi and 910 F, easily convertible to oil firing. About 30 per cent of the coal is burned in suspension, the remainder on the forward moving grate; fly ash and grit from the superheater hopper and grit arrester are returned with part of the secondary air into the furnace. The 15 Mw turbine has two extraction points at 75 and 20 psi. The make-up water is treated in a hydrogen-ion starvation, base-ex-

change plant with caustic soda addition for pH adjustment and passed through two evaporators. The condensate and make-up water are passed through a deaerator to reduce the O_2 content to 0.005 cc/l.

Materials and Manufacturing Processes

A Comparative Method for Testing Graphite for Nuclear Reactors. I. F. Zezerun. *Kernenergie* 1960, **3** (June), 538–42 (in German).

A method worked out in Russia is described for assessing the suitability of a graphite for use in reactors based on a comparison of the weakening of the flux of thermal neutrons by the graphite under test and a standard graphite.

Relationship between Thermal Properties and Atomic Molecular Structure of Carbon in Homogenising Graphitisation. V. I. Kasatockin, V. K. Zamoluev and A. T. Kaverov. *Kernenergie* 1960, **3** (June), 570–2 (in German).

Results of Russian studies of specific heat, thermal conductivity and x-ray determination of degree of graphitization of petroleum coke under isothermal conditions are reported.

Absorption Cross-Section of Graphite P. F. Nichols. *Nucl. Sci. Engng.* 1960, **7** (May), 395–99.

American, French and British graphites were tested and their absorption cross-section measured and compared with values obtained in their countries of origin.

Silicon Nitride. N. L. Parr. *Research* 1960, **13** (July), 261–9.

Silicon nitride has excellent oxidation resistance up to 1600 C, is dimensionally stable, resistant against thermal shock and can be produced simply and cheaply. Its properties are tabulated and discussed.

A Note on the Relationship between Chemical Composition and Hot-Cracking in Mild and Alloy Steels. W. K. B. Marshall. *Brit. Weld. J.* 1960, **7** (July), 451–3.

Certain elements (e.g., sulfur, phosphorus and silicon) present in the steel are now recognized as primary crack formers, while others depending on their solubility in austenite and ferrite may increase or reduce the tendency to hot-cracking.

Effect of Elevated-Temperature Exposure on Heavy Section Pressure-Vessel Steels. A. W. Pense, J. H. Gross and R. D. Stout. *Weld. J.* 1960, **39** (June), 231s–5s.

Studies on the embrittlement of carbon and alloy steels due to aging at room temperature and at 500 and 700 F.

Effect of Chromium Depleted Surface on Corrosion Behavior of Type 430 Stainless Steel. R. V. Trax and J. C. Holzwarth. *Corrosion* 1960, **16** (June), 105–8.

Causes of depletion, its effect on corrosion behavior and means of alleviating depletion are considered.

Growth of Uranium Rods in Agressive Gas Media. I. V. Batenin, A. N. Rudenko and B. V. Sarov. *Kernenergie* 1960, **3** (June), 532–5 (in German).

Russian investigations into the growth of uranium in air, nitrogen and carbon monoxide as a function of temperature, gas pressure, rod diameter and previous state of oxidation of the rod surface are reported. A possible mechanism of this growth is proposed.

Modern Welding Methods Applied to Power Station Engineering. D. P. Tait. *Brit. Pwr. Engng.* 1960, **1** (July), 41–4.

Some of the latest developments in arc welding pressure vessels and pipes are described.

Ultrasonic Welding. B. E. Noltingk. *Weld. Met. Fabr.* 1960, **28** (July), 260–6.

Some recent British investigations in the field of ultrasonic welding, its advantages and difficulties experienced are reported. The various techniques developed for spot and seam welding are described and illustrated by examples. Thin materials, dissimilar metals or those of unequal thickness are particularly suited to ultrasonic welding.

Piping. T. W. Edwards. *Power* 1960, **104** (June), 51–66.

This survey deals with: (1) Materials (steel cast iron, wrought iron, copper alloys, copper tubing, others); (2) supports and fittings; (3) fluid losses; (4) ASA piping standards.

Instruments and Controls

Automatic Boiler Control. F. Marchand. *Tech. Mod.* 1960, **52** (May), 300–3 (in French).

Recent trends in French power station control equipment are discussed. The "synchrolisseur" has been developed, an electronic instrument, which is used to set servomotors in their correct position.

The Control of Sulzer Monotube Steam Generators with Reheating. M. Diethelm. *Sulzer Tech. Rev.* 1959, **41**, No. 4, 3–9.

The English version of the paper previously abstracted (abstract 4371, 1959).

Control of Power Reactors—1. R. H.

Campbell. *Nucl. Pwr.* 1960, **5** (July), 68–72.

The problems to be considered in the design of controls for power reactors are set out.

Recording Electrical Resistance Corrosion Meters. E. C. Winegartner. *Corrosion* 1960, **16** (June), 99–103.

The design of the instrument, precautions to be taken and results obtained are described.

Radioactive Equipment for Direct Measurement of Coal-bunker and Reservoir Levels. V. G. Segalin, P. V. Lopotskii and S. I. Libson. *Elekt. Stantsii* 1960 (April), 20–30 (in Russian).

A radioactive source of what appears to be an alloy of cobalt, barium and nickel in the form of a vertical wire in a protective sheath and with radioactivity uniformly distributed along its length is located inside the bunker. The radiometric receiver is fixed on the outer wall or inside the bunker or reservoir. Formulas derived show that the intensity of radiation induced by the radiometric equipment is related only to the length of the radioactive wire not covered by coal, i.e., with the level of filling of the bunker or reservoir. The equipment can operate satisfactorily in very dusty and humid conditions, these factors having little effect upon the measurements.

From *C.E.G.B. abstract.*

Nuclear Energy

World Power Conference. Anon. *Nucl. Engng.* 1960, **5** (July), 317–9.

A digest of the papers dealing with all aspects of nuclear power presented to the Madrid meeting is given.

Present State of Projects for Nuclear Power Stations in the European Community. H. Schult. *B.W.K.* 1960, **12** (June), 252–4 (in German).

In the countries of the European community about 75 research and experimental reactors are in operation or under construction. A brief survey of research and power station reactors in France, Germany, Holland, Belgium, Italy and Gt. Britain is presented.

The Engineering Design of Power Reactors. N. J. Palladino and H. L. Davis. *Nucleonics* 1960, **18** (June, 85–110.

The subject is discussed under the headings: (1) Conceptual design; (2) steps in the design process; (3) reference design; (4) plant conceptual design; (5) design criteria and initial estimates; (6) catalogue of design criteria for power reactors; (7) parametric studies; (8) core and

vessel layout; (9) temperature flattening; (10) reference fuel design and development; (11) reactivity requirements and control rods design.

The Marine Boiling Water Reactor. D. R. Smith. *Brit. Pwr. Engng.* 1960, **1** (July), 26–33.

The design worked out by the Nuclear Power Group for a 65,000 ton tanker with a 20,000 shp power unit is described. The reactor power is 60 Mw and it operates with a coolant at 1000 psi and an outlet temperature of 546 F, fuel pellets enriched by 2.5 per cent and a maximum temperature of 3992 F and a maximum can temperature of 572 F. The steam is passed directly to a hp and a l-p turbine in series.

The Brown Boveri-Krupp High-Temperature Gas-Cooled Reactor. R. Schulten and E. Jantsch. *Brown Boveri Rev.* 1960, **47** (Jan./Feb.), 88–96.

The prototype reactor with a net electrical output of 15 Mw is of the breeder type using in the second phase uranium-carbide and thorium-carbide graphite spheres freely heaped in the core. The coolant gas is He or He + Ne entering at 200 C and leaving at 850 C at a pressure of 10 kg/cm² generating steam at 505 C and 75 kg/cm² at a rate of 60t/h. The reactor, core, fuel elements, gas and steam circuits, controls given.

Dragon Objective. Anon. *Nucl. Engng.* 1960, **5** (July), 300–1.

The objectives are steam conditions comparable to those in conventional power stations, compact core and low capital costs and exploitation of the thorium-U233 breeder cycle. The differences between this graphite moderated and helium-cooled reactor the Calder Hall AGR are set out.

Dragon General Description. Anon. *Nucl. Engng.* 1960, **5** (July), 302–5.

This includes: (1) Core; (2) control; (3) reactor vessel; (4) coolant; (5) charge machine; (6) fission product removal; (7) shielding and containment; (8) ventilation; (9) auxiliary buildings and supplies.

Dragon Control System. J. R. Dean. *Nucl. Engng.* 1960, **5** (July), 306–9.

Dragon Fuel Elements. E. Smith. *Nucl. Engng.* 1960, **5** (July), 310–3.

Dragon Graphite. R. A. U. Huddle, P. A. P. Arragon and M. S. T. Price. *Nucl. Engng.* 1960 **5** (July),, 314–5.

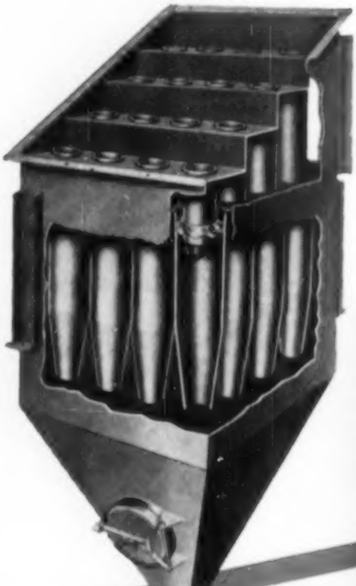
Hydrogen as a Reactor Coolant. P. N. Garay. *Nucl. Pwr.* 1960, **5** (July), 96–9.

The properties of hydrogen which favor its application and also its disadvantages are set out.

Advertisers' Index

(Continued on page 67)

13 BIG REASONS WHY MULTICLONE FLY ASH COLLECTORS



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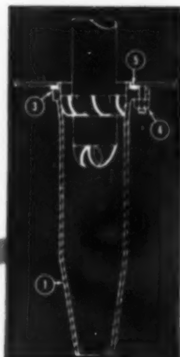

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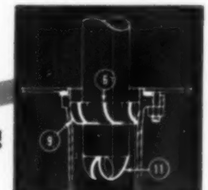

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